Nutritional status of geologically different vineyards in Helderberg

by

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Declaration

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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SUMMARY

Little scientific information regarding the effect of different geological parent materials on grapevine performance is currently available in South Africa. This aspect is of special significance for the Helderberg area, where parent material may change from granite to shale over a short distance. This results in shale- as well as granite-derived soils often occurring within the same vineyard. The objectives of this study were to (i) quantify the nutritional status and other soil properties of different parent materials (shale and granite) and overlying soils (ii) investigate the impact of geological differences in the soil on the vine nutritional status and certain vine parameters. This study was done over two seasons (2006/2007 and 2007/2008). Two Sauvignon blanc and two Cabernet Sauvignon vineyard blocks were selected at two different localities for each cultivar in the Helderberg area, South Africa. Shale- and granite-derived soils were identified within each block.

Kaolinite was the dominant mineral, whereas quartz and feldspar were sub-dominant. Traces of mica were also present in some shale- and granite-derived soils. Granite- contained significantly higher contents of coarse sand than shale-derived soils, whilst the opposite occurred in terms of fine sand. These differences affected the water holding capacity, in general making it higher in shale- than granite-derived soils. Shale-derived soils had higher concentrations of total K but granite-derived soils had a higher ability to release K as they contained higher concentrations of soluble K. The Q/I parameters, potential buffering capacity of K (PBC^K) and equilibrium activity ratio of K (AR^K) showed no consistent responses to geological differences.

Potassium concentrations were higher in the leaf blades (obtained before harvest in 2007) from Sauvignon blanc grapevines on granite- than on shale-derived soils. Potassium concentrations in the Cabernet Sauvignon juice (obtained in 2007) tended higher in juice from granite- than from shale-derived soils. In 2008, K concentrations tended higher in juice from shale- than from granite-derived soils for both cultivars. The pH of the Sauvignon blanc juice (obtained in 2008) tended higher in juice from shale-than from granite-derived soils, thus corresponding with the K concentrations in the juice in this season. Nitrogen concentrations were higher in Cabernet Sauvignon juice (obtained in 2007) and Sauvignon blanc juice (obtained in 2008) from shale- than from granite-derived soils. In terms of vine water status, vines on granite-derived soils appeared more stressed than those on shale-derived soils in both seasons at one of the vineyards.

In these Sauvignon blanc and Cabernet Sauvignon vineyards, the K nutritional status was not affected by geology in a consistent manner but there were some noticeable tendencies for a specific cultivar during certain seasons. On account of vines being planted on shale- and granite-derived soils within the same block, soil preparation was done similarly for both soils, and they were exposed to similar irrigation schedules, canopy management strategies and climatic conditions. Therefore, there is a high probability that all these practices may have negated the effect of geology on the K status of soils and especially on juice K concentration at the time of harvest. It was clear that seasonal differences and fertilisation affected the nutritional status of the vines more than geology.

OPSOMMING

In Suid-Afrika is daar tans min wetenskaplike inligting oor die effek van verskillende geologiese moedermateriale op die prestasie van wingerd beskikbaar. Hierdie aspek is veral van belang in die Helderberg-area, waar moedermateriaal oor 'n baie kort afstand van graniet na skalie kan wissel. Dit lei daartoe dat skalie-, sowel as granietgronde, dikwels binne dieselfde wingerd voorkom. Die doelwitte van die studie was om: (i) die voedingstatus en ander grondkundige eienskappe van die verskillende moedermateriale (skalie en graniet) en oorliggende gronde te kwantifiseer (ii) die impak van geologiese verskille in die grond op wingerd se voedingstatus en sekere wingerdkundige parameters, te ondersoek. Hierdie studie is oor twee seisoene (2006/2007 en 2007/2008) gedoen. Twee Sauvignon blanc en twee Cabernet Sauvignon wingerdblokke is geselekteer by twee verskillende lokaliteite vir elke kultivar in die Helderberg-area, Suid-Afrika. Beide skalie- en granietgrond is binne elke blok geïdentifiseer.

Kaoliniet was die dominante mineraal, met kwarts en veldspaat sub-dominant, terwyl spore van mika ook in beide skalie- en granietgronde gevind is. Granietgronde het betekenisvol hoër hoeveelhede growwe sand bevat, terwyl skaliegronde meer fyn sand bevat het. Hierdie verskille het 'n effek op waterhouvermoë gehad en daartoe gelei dat waterinhoude oor die algemeen hoër was vir skaliegronde. Skaliegronde het groter hoeveelhede totale K bevat, maar granietgronde se vermoë om K vry te stel was hoër, omdat hulle 'n hoër konsentrasie oplosbare K bevat het. Die Q/I parameters, potensiële buffervermoë vir K (PBC^K) en ewewig aktiwiteitsverhouding vir K (AR^K), is nie op 'n konsekwente wyse deur geologiese verskille beïnvloed nie.

Vir die Sauvignon blanc wingerde was kalium konsentrasies in blaarskywe (gemonster voor oes in 2007) hoër vir graniet- as vir skaliegronde. Kalium konsentrasies in die sap vanaf Cabernet Sauvignon (gemonster in 2007) het hoër geneig vir granietgronde. In 2008 het die kalium konsentrasies, vir beide kultivars, hoër geneig in sap vanaf skaliegronde. Gedurende dié seisoen het die pH van sap ook hoër geneig vir Sauvignon blanc vanaf skaliegronde, wat dus ooreenstem met die K inhoud van die sap. Stikstof konsentrasies was hoër in sap vanaf skaliegronde vir Cabernet Sauvignon (2007) en vir Sauvignon blanc (2008). In terme van die wingerde se waterstatus, het stokke op die granietgrond, by een van die lokaliteite, geneig om gedurende beide seisoene onder groter stremming te wees op graniet as op skaliegrond.

In hierdie Sauvignon blanc en Cabernet Sauvignon wingerde, is K voedingstatus nie op 'n konsekwente wyse deur geologie geaffekteer nie, maar gedurende sommige seisoene was daar wel duidelike tendense vir 'n spesifieke kultivar. Omdat die stokke binne dieselfde blok op skalie- en graniet gronde geplant is, was grondvoorbereiding eenders vir die twee grondtipes terwyl besproeiingskedule, lowerbestuur en klimaatstoestande ook identies was. Daar is dus 'n hoë waarskynlikheid dat al hierdie faktore daartoe kon bygedra het dat die effek van geologie op die K status van van gronde versluier is, veral die effek op die K inhoud van sap teen oestyd. Dit was duidelik dat seisoenale klimaatsverskile en bemestingspraktyke 'n groter effek as geologie op die voedingstatus van die wingerd gehad het.

This thesis is dedicated to

My parents (my late father, Dinwayini and mother, Fikile), my sisters (Lindiwe, Lungile, Nikiwe, Nompumelelo Shange), my only brother (Sifiso) and his family (Thabile and Anesu).

BIOGRAPHICAL SKETCH

Philisiwe Lawrancia Shange was born in KwaZulu Natal, on 26 September 1980. She enrolled for a degree in BScAgric (Viticulture and Soil Science) and graduated in March 2005. In 2005, Philisiwe enrolled for a degree HonsBScAgric (Viticulture) and graduated in December 2005. From June 2005 till present, she is employed by the, Agricultural Research Council-Infruitec Nietvoorbij as a technician/ junior researcher in grapevine nutrition studies. In 2006, she enrolled for the degree MScAgric (Viticulture).

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PREFACE

This thesis is presented as a compilation of five chapters. Each chapter is introduced separately and is written according to the style of the South African Journal of Oenology and Viticulture.

Chapter 1	**General Introduction and project aims**
Chapter 2	**Literature review** The role of geology and related factors on the potassium status in vineyards.
Chapter 3	**Research results** Nutritional status of geologically different vineyard soils.
Chapter 4	**Research results** Grapevine nutritional status of geologically different sites.
Chapter 5	**General discussion and conclusions**

CONTENTS

Chapter 1

Introduction and project aims

CHAPTER 1: INTRODUCTION AND PROJECT AIMS

1.1 INTRODUCTION

1.1.1 Role of geology in grapevine cultivation and wine production

The concept of viticultural terroir defines relatively homogenous topographical (e.g. slope and land form), pedological (geology-bedrock, overlying soils and soil forming processes) and climatic attributes (Carey *et al*., 2001), which are transferred to the vine and progress to wine after some manipulations in the cellar. Geology includes the underlying parent material, the resulting soil after weathering, overlying soils and variations in topography. According to Conradie *et al*. (2002), in France geology has been primarily used to identify the "Unités Terroir de Base" in the Mid-Loire Valley. In South Africa geology has not yet been used for terroir demarcation as much as climate has been used. In the Western Cape region where most vineyards for high quality wines exist, soils developed from a variety of geological materials, the most important being shales, granites and sandstones (Bargmann, 2005). However, due to various soil forming processes most vineyard soils are now made up of mixtures of different geological materials.

The vine-soil relationship is a fundamental part of the concept of terroir (especially wine quality) and it is also the least understood and overlooked in viticulture terroir (Saayman, 1992; Mackenzie & Christy, 2005). Some studies have been done in South Africa but there were no direct relationships found between soil parent material and grapevine growth, wine quality and / or wine character (Van Schoor 2001; Conradie *et al*., 2002). Geology *per se* may not directly affect wine style; however, the physical and probably chemical attributes of the resultant soil may affect soil properties which are of importance to wine quality or style (Conradie *et al*., 2002; Maltman, 2008).

Quantification of the effects of chemical composition of soil on plants resulted in only poor relationships between relative concentrations of elements in the soil and in the plants (Brun *et al*., 2001; Mackenzie & Christy, 2005). Manipulation of available nutrients by cover crops (Fourie *et al*., 2007) and fertilizers may make the quantification of the contribution of soil nutrients to that of the plant more difficult (Maltman, 2008). Furthermore, once nutrients are taken up from the soil, genetic properties of rootstocks and scion material (Downton, 1977), environment and viticultural practices (Iland, 1988) can manipulate the distribution of elements within the vine.

Due to all these factors influencing the nutrient status of the soil and the vine, the inorganic status of the must can hardly be expected to be similar to that obtained in the vineyard soils (Maltman, 2008). Furthermore, during the process of vinification probably much less of nutrients from the soil end up in the wine as the addition of other wine making ingredients e.g., fining agents, thus further decreasing concentrations of the nutrients taken from the soil (Almeida & Vasconcelos, 2003). In an attempt to relate wine to its place of origin, wine finger printing research has been carried through with little success (Almeida & Vasconcelos, 2001; Ettler *et al*., 2005). Therefore, when it comes to directly relating chemical composition of the vineyard soil to that of the wine, little success has been attained, pointing towards the difficulty of directly linking soil elements to those of wine (Maltman, 2008). For scientific purposes it is very important to determine or quantify any links that exist between soil and grapevine performance and therefore wine quality or style.

1.1.2 Potassium and grape composition

In South African vineyard soils, potassium (K) and nitrogen (N) may have a significant effect on wine quality, especially if no serious deficiencies of other essential elements exist (Saayman, 1992). Furthermore, soil K levels may have a substantial effect on the acid balance of the grape juice and therefore wine pH (Conradie & Saayman, 1989). Granite-derived soils have been reported to release more K (Wooldridge, 1988), while soils originating from phyllitic shales have been found with lower K levels (Conradie *et al*., 2002). Furthermore, granite-derived soils were found to have a low ability to retain K as Italian rye grass grown on them absorbed a substantial amount of K (Wooldridge, 1988). Even though crops differ greatly in their responsiveness to K, in the absence of excessive fertilization, grapevines grown on chemically weathered granitic soils may consume excessive amounts of K as well (Conradie *et al*., 2002; Wooldridge, 2005).

Potassium is a macronutrient taken up by plants in moderate to large amounts and its shortage or excess in soil may affect crop yield (Wild & Jones, 1988) and quality to a large extent. During grapevine cultivation, an adequate nutritional status (including enough K) of the grapevine is needed for optimum production and better wine quality (Conradie & Saayman, 1989). Soil K availability tends to induce an increase in juice pH (Iland, 1988; May, 1994). Excess K in the grape berries may decrease free tartaric acid, which results in a rise of pH in the grape juice, must and wine (Boulton, 1980; White, 2003). The pH is known as one of the most important measures of juice and wine acidity (Boulton, 1980) and a major quality factor in the wine industry (Ruhl, 1989). According to Garcia *et al*. (2001), lack of acidity as reflected by a flat taste in wines investigated, was a problem partially due to a high K content in the grapevine. High K concentrations (27-71 mmol ℓ^{-1}) and pH (3.7-4.3) levels in Australian red wines are negative characteristics indicated by poor colour (red wines), low acidity and stability, making the wine more susceptible to oxidative and biological spoilage (May, 1994). Measures to adjust pH during the vinification processes include tartaric acid addition (Mpelasoka *et al*., 2003). If the K levels are so high that precipitation of K-bitartrate occurs, controlling this problem becomes more difficult as it creates more waste to manage and increases input costs (Mpelasoka *et al*., 2003).

Some studies have been done in South Africa aiming to understand the relationship between K in the soil and grapevine performance and wine style or quality (Conradie & Saayman, 1989; Van Schoor, 2001; Conradie *et al*., 2002; Engelbrecht & Saayman, 2005; Agenbach, 2006). It can be assumed that if the soil is the sole source of K, manipulation of the source will result in better manageable K levels in the berry. However, no direct links are known between soil K and grapevine or berry K. This could be due to many other factors related to soil, rootstocks, scions, environment and vineyard management practices that affect the availability of K in the soil, its uptake and distribution once in the grapevine (Mpelasoka *et al*., 2003). It has been acknowledged that the relationship between soil K and vine K is not clear and needs to be better understood (Iland, 1988; Mpelasoka *et al*., 2003). Therefore, with the purpose of better managing future K problems in the wine industry, the effect of soil parent material on soil K, grapevine K and berry K needs to be quantified and understood.

1.2 AIMS AND OBJECTIVES

The Helderberg area historically has vineyards laid out on geologically different soils (i.e. granite- and shale-derived). Moreover, soils from these two rock types often exist within the same vineyard block and in many cases in the same vine row. The research described in this study aims to quantify the K supply of geologically different soils, derived from shale and granite rock types. Furthermore, it investigates the manner in which some soil, grapevine and vineyard management related factors affect the accumulation of K in the grapevine leaves, petioles and the berry.

The overall objective of this study is to quantify the ability of granite- and shale- originating soils to supply K. More specifically:

1. To determine the differences in soil nutritional (especially K) status due to differences in parent materials within vineyard soils and the soil factors that could possible affect soil K availability.
2. To determine the differences in the grapevine K nutrient status with the assumption that they were induced by differences in parent materials.
3. To determine the differences in other attributes of the grapevine, possibly due to the differences in parent materials, and thus differently affecting the distribution of K in the grapevine and the berry.

The main hypothesis that will be tested in this study is that rock type, in its ability to affect the physical and chemical characteristics of the soil, affects soil K and therefore grapevine K levels. However, other factors in the soil must also be taken into consideration, as they may also contribute to the availability of soil K and some grapevine and vineyard management factors may also affect the distribution of the K within the vine. The following specific questions were addressed:

1. Does K supply differ between the shale- and the granite- derived soils?
2. Does K supply affect grapevine K levels in the leaves, petioles and berry?
3. Are other soil, vine and grape juice properties affected by geological origin?

Finding answers to these questions involved comprehensive analysis of the literature on the role of geology in grapevine cultivation and wine production as well as the role of K in grape composition. It also involved field investigation to quantify K levels in the soil and in grapevines. The research aims to contribute to an improved understanding of the manner in which soil parent material, in terms of K supply, can affect petiole K; leaf K and berry K as it affects wine pH to a certain extent.

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Chapter 2

Literature review

The role of geology and related factors on the potassium status in vineyards

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Geology affects the origin of vineyard soils as they are derived from specific rock parent materials. Consequently it has been used in France as a primary key to identify some terroir units (Seguin, 1986). In South Africa, geology of the Western Cape coastal wine grape growing region is very complex and varies over short distances (Conradie *et al*., 2002). Furthermore, studies regarding geology as a soil forming parameter and a possible predetermining character to vine growth and wine character have been attempted (Van Schoor, 2001; Conradie *et al*., 2002). South African vineyard soils have developed from a variety of geological materials which include shales, granites and sandstones (Bargmann, 2005; Wooldridge, 2005a). In addition, the K contents of these geological materials have been found to differ (Wooldridge, 2005b), thus drawing attention to the K status of vineyard soils derived from such rocks. In cases where there are no deficiencies of other essential elements in the soil, K is among the elements which may have a definite effect on wine quality (Saayman, 1992).

Soil K levels may have a significant effect on the acid balance in the grape juice and on the pH of the resulting wine (Conradie & Saayman, 1989; May, 1994). According to Garcia *et al*. (2001), the lack of acidity in their French wines was partially due to a high K content. Furthermore, high K concentrations in the must have been reported to result in increased wine pH (Poni *et al*., 2003) and producing wine with a low acidity and a flat taste (May, 1994; Conde *et al*., 2007). In order to lower pH, tartaric acid (TA) is normally added, especially in countries such as Australia (Mpelasoka *et al*., 2003). However, although this problem can be controlled, it increases the cellar input costs. In this literature review, important factors that affect the availability of K in the soil are discussed in order to get a better understanding of the ways in which soil K, juice composition and wine quality may be affected by geology. Furthermore, the manner in which other factors (climate, soil management and viticulture related) could enlarge or decrease the “K problem”, is also discussed.

2.2 IMPORTANCE OF POTASSIUM IN GRAPEVINES

Potassium was recognized as an essential plant nutrient by Von Liebig in 1840 (Kirkman *et al*., 1994). It is one of the most abundant cations in plant tissues and highly mobile through plant membranes (Mpelasoka *et al*., 2003). In grapevines, it plays a major role in physiological-biochemical processes that have to do with activation of enzymes, cellular membrane transport, neutralization of charge, translocation of assimilates such as cations, anions and sugars and regulation of the osmotic potential (Lindhauer, 1986; Conde *et al*., 2007). Grapevine leaves, with relatively low K concentrations, tend to have high concentrations of diamine putrescine (White, 2003). Also, in cases of low K availability, photosynthesis in the leaves may be inhibited and a low K to nitrogen (N) ratio may be induced, further promoting what might appear to be a K deficiency (White, 2003). Where high K concentrations occur, an undesirable increase in the ratio of malic to tartaric acid of the must (White, 2003) and wine pH (Conde *et al*., 2007) may result. High titratable acidity and pH have been associated with high K levels in juice, probably due to high levels of malate, as large concentrations of malic acid and K contribute in establishing high pH (Hale, 1977). Generally, K has a considerable effect on the acid balance in grape juice pH and wine quality (Boulton, 1980a; Conradie & Saayman, 1989), thus deserving attention when it comes to wine grape production.

Grapevines absorb K from the surrounding soil solution by a simple diffusion mechanism or an energy-driven system or a combination of both (Iland, 1988; Wood & Parish, 2003). During K absorption, a possibility of the presence of the enzyme system, K/H adenosine triphosphatase (ATPase) in grapevine roots has been reported (Boulton, 1980a). This enzyme system may assist in the uptake of monovalent metal cations from the soil. Once K (and other cations) is absorbed, it is distributed to all parts of the vine via the phloem and the xylem streams (Conde *et al*., 2007). Potassium (and Na) is more readily mobile in the phloem stream than in the xylem stream (Iland, 1988). The uptake and distribution of nutrient elements within plants only happens at specific times, especially during the period when the plant is most active. Schaller (1999) found that K was taken up steadily from fruit set to harvest by the variety "White Riesling".

In a study done under South African conditions for Chenin blanc planted in sand culture by Conradie (1981a), K was absorbed from about three weeks after bud burst until four to five weeks after harvest but not during leaf fall (Fig. 2.1). From vèraison to harvest, K concentration in clusters increased, and clusters accumulated more K than that absorbed. The post harvest period was found to be the most important time for the accumulation of K reserves, especially in the roots. The accumulation of K in the roots during post harvest and the manner in which K is translocated from leaves, bark and wood to fruit prior to harvest is normally similar in all deciduous plants (Kotze & De Villiers, 1989).

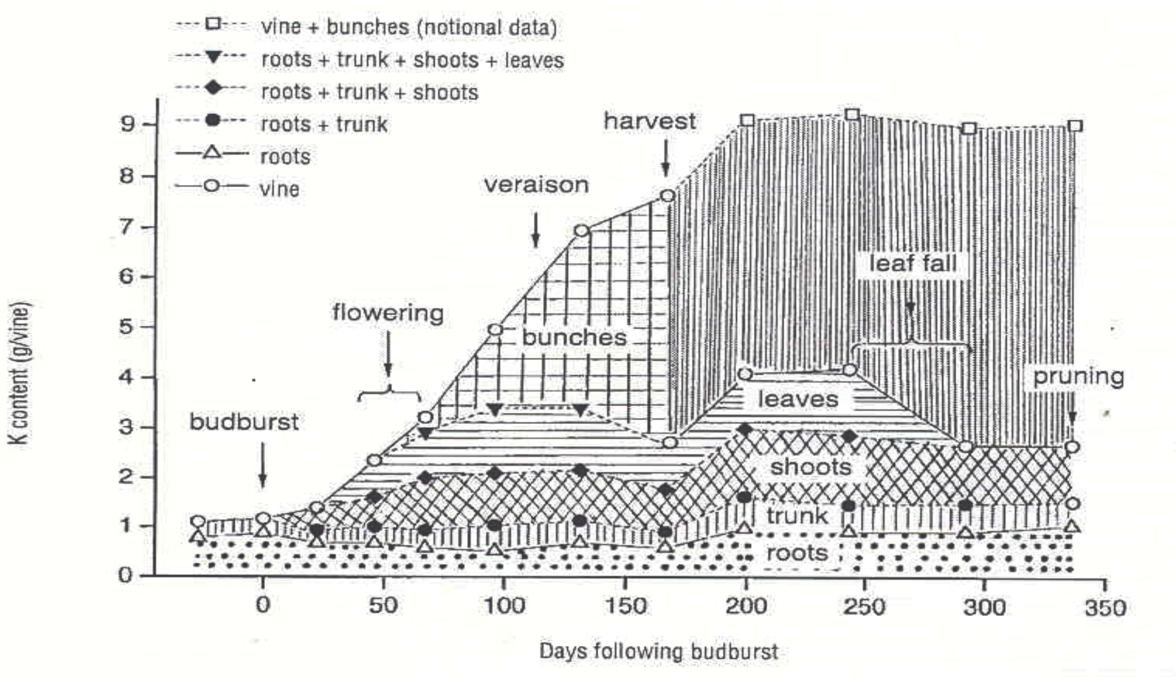

Figure 2.1 Seasonal accumulation of K in different organs of Chenin blanc/99R grapevines (Mpelasoka *et al*., 2003; adapted from Conradie, 1981a).

Potassium is normally translocated from old to young plant tissues (Mengel & Kirkby, 1987; Kotze & De Villiers, 1989). Within the plant, most of the K is transported in the transpiration stream to the mature leaves via the xylem. Potassium is than stored in the vacuoles of a number of specific storage cells found within the mature leaves (Wood & Parish, 2003). When K is required for growth, it is then transferred to the phloem within mature leaves so that it can be mobilized to the growing organs e.g., shoot tips, immature leaves and fruit (Mpelasoka *et al*., 2003). The faster the growth rate, the more of a sink these organs become, and they are likely to receive more K (Kotze & De Villiers, 1989).

2.3 BERRY POTASSIUM AND WINE QUALITY

The amount of berry K increases over the season (Conradie, 1981a). When ripening starts, the berries become priority sinks for K (Iland, 1988). However, K accumulation has been found to be slow during the pre-véraison phase but increased during post-véraison berry enlargement (Rogiers *et al*., 2000). Hanana *et al*. (2007), observed an increase in vacuolar K^+ accumulation during véraison and post véraison stages. If berry growth and berry K accumulation are maintained at similar rates, berry K concentration may remain relatively constant (Mpelasoka *et al*., 2003). However, if the rate of K accumulated in the berry exceeds the rate of berry growth, berry K concentration will increase. Factors that affect rate of berry growth and/or rate of K accumulation in the berry such as cultivar, crop load, climate and cultural practices, determine the extent of the K concentration in berries (Mpelasoka *et al*., 2003).

A sharp increase in berry K is normally observed after the lag phase, at the onset of ripening (Conradie, 1981a; Wood & Parish, 2003). Hrazdina *et al*. (1984), found an increase in K^+ concentration from approximately 1700-2300 mg ℓ^{-1} immediately after véraison. During this period, the berry softens, changes colour and chemical composition (Mpelasoka *et al*., 2003). A rise in sugar content and a decrease in organic acid content while berry growth occurs are also observed. In the berry, K is the major cation present (Iland, 1988), thus playing a major role in comparison to other cations (Conradie, 1981b). Potassium is distributed differently within the grape (Ribéreau-Gayon *et al*., 2003), with K concentration being higher in the skin than in the pulp and the seeds (Walker, *et al*., 1998). The presence of ATPase activity (possibly found in the roots as well) has been suggested to be present in the berries to enable cation transport across the plasmalemma in exchange for internal protons derived from the organic acids (Boulton, 1980a). The exchange of protons for K^+ (and other cations) has been reported to be partly the reason for the increase in juice pH and a decrease in juice TA observed during the ripening stages (Iland, 1988).

The concentration of juice K at harvest in the grape berry is one of the principal determinants of juice pH. Juice pH is expressed as a function of the titratable acidity, the K and Na contents and tartaric acid to malic acid ratio (Boulton, 1980b). Excessive K^+ uptake by berries at harvest has been associated with high juice pH (Iland, 1988, Conde *et al*., 2007). Grape juice pH is a critical parameter when it comes to determination of wine quality (Conde *et al*., 2007). Grape juice with a high pH (> 3.5) is associated with unstable musts, which are more susceptible to oxidative and microbial spoilage and high pH wines which are characterized by low acidity and a flat taste (May, 1994; White, 2003). Also, under high K levels, the stoichiometry exchange of tartaric acid with protons and also with K^+ may result in the formation of largely insoluble K-bitatrate. Consequently, a decrease in free acid, tartaric acid to malic acid ratio and an increase in the overall pH may occur (Conde *et al*., 2007).

High juice and wine pH may also lead to a decrease in colour quality and stability of red wines, caused by reduced anthocyanin ionization likely to occur at high pH levels (Iland, 1988; Conde *et al*., 2007). Anthocyanins are located in the berry skin, where K concentration is generally the highest in comparison to that of the pulp and seeds. Berry K levels are important in the making of red wines and white wines that use skin contact (Iland, 1988; May, 1994). In wine making, the skin is left in the must for some period after crushing for the extraction of anthocyanins and this is when more K is extracted, influencing the balance of acidity parameters, thus modifying pH and TA values. Therefore, knowledge of the factors involved in K availability and transport from the soil to the vine and its accumulation in the berry is crucial in order to develop strategies which may reduce its excessive accumulation in grape berries and thereby improve fruit and wine quality.

2.4 FACTORS AFFECTING THE POTASSIUM STATUS IN VINEYARDS

Factors that may affect accumulation of K in the berries are related to climate, soil, grapevine and viticultural practices. However, according to Mpelasoka *et al*. (2003), interrelationships among the effects of these factors on grapevine K levels are likely to complicate any simple explanation for the regulation of K and accumulation in grape berries.

2.4.1 Climate

Temperature: Temperature is probably the most important factor influencing grapevine development, growth (Coombe, 1987), nutritional composition and fruit quality (Bonomelli *et al*., 2006). However, a problematic lack of acidity has been associated with high K levels in grapes and red wines from hot viticultural areas (May, 1994; Agenbach, 2006). In such areas high ambient temperatures during the growing season may be detrimental to leaf photosynthesis which may be accompanied by enhancement of K transport to the berries (Iland, 1988). Bonomelli *et al*. (2006), found significantly higher concentrations of K in bunches under high light conditions. The rise in berry juice pH during ripening is largely associated with high berry K levels and malic acid degradation. Problems may also occur under cool conditions if temperatures are too low. A decrease in the photosynthetic rate, especially if it occurs during the late stage of ripening, can be induced under cool conditions (Iland, 1988). A rise in juice pH, in the cool areas, is likely to be due to K movement only, as malate respiration would normally be decreased under cooler conditions (Iland, 1988). Dundon *et al*. (1984) found that wine K content was high in wines from cool vineyards. On the other hand, cool climates have been found to induce reduced K uptake from the soil. Under cool climates, excessive soil wetness is likely to inhibit uptake of K by the roots (White, 2003).

Wind: Exposure to wind can result in significant variability in grapevine physiology and berry composition (Pienaar *et al*., 2006). Moderate winds higher than 3-4 ms^{-1} may cause stomatal closure in the leaves, which leads to limitation of carbon dioxide (CO_2) uptake and photosynthesis (Bonnardot & Carey, 2006). When CO_2 is not actively assimilated, especially in wind facing vines, K levels in the phloem may increase, and become available for loading into the grape berries. Limitation of photosynthesis leads to a reduction in sugar production and a likely movement of leaf K to the berry (Iland, 1988). Vines exposed to the wind have been found with higher berry K contents compared to those unexposed to wind (Pienaar *et al*., 2006). Furthermore, according to Iland (1988), high winds are likely to lead to high transpiration rates, which may exceed water uptake, resulting to stomata closure.

Humidity: Low relative humidity has been found to enhance the average transpiration rate in grape vines (Rühl, 1992). Furthermore, at 90 % relative humidity transpiration was found lower than at 30 % relative humidity.

2.4.2 Soil

The role of soils and bedrock geology has been acknowledged as a fundamental component of terroir (Bargmann, 2005). However, the role of soil is considered secondary to that of climate (Saayman & Kleynhans, 1978) and canopy management (Lanyon *et al*., 2004) in determining wine character. The possibility of a role of geology (parent material) in affecting the K status in SA viticulture has been raised by Van Schoor (2001) and Engelbrecht & Saayman (2005). High levels of K in the soil have been associated with high levels of K in grapes and consequently undesirably high pH in red wine (May, 1994). However, no clear relationships have been observed between soil K and grapevine K (Iland, 1988; Mpelasoka *et al*., 2003).

Soil K: Potassium (K) is one of the macronutrients that is commonly found in sufficiently short supply in the soil in such a manner that it limits crop growth (Wild & Jones, 1988). In the soil, K is found in its common ionic form, K^+ (White, 2003). The average total K content in the soil is about 2.3 % (Cotton *et al*., 1995) and exists in four different forms i.e. structural, fixed, exchangeable, and solution (Cox *et al*., 1999, Di Meo *et al*., 2003). These different forms of K occur in a dynamic equilibrium and are not all available for plant uptake (Mengel & Kirkby, 1987). Solution K and exchangeable K are readily available to plants, whilst non exchangeable K (fixed K and structural K) is slowly available and makes up the main K reserve of the soil. The plant availability of soil K is controlled by dynamic interactions among these different pools of K (Wang *et al*., 2004). In addition, K availability depends on the rate of K^+ uptake by roots and certain soil characteristics such as mineralogy, texture, cation exchangeable capacity (CEC), moisture, temperature, pH, Ca, Mg and K fixation (Kirkman *et al*., 1994; Mpelasoka *et al*., 2003).

Geology (parent material): Soils have been described as complex materials that reflect the variability of the parent rock material and the organic residues they have originated from (McBride, 1994). Nevertheless, their elemental composition, particle size, and mineralogy can be related to a certain extent to the nature of the parent material and its intensity of weathering. In Figure 2.2, the importance of soil age and origin is illustrated (McBride, 1994). The old soil (oxisol) from the tropics is highly weathered and has developed with a loss of large amounts of silica (desilication) and basic cations (Ca, Mg, K, Na) that were initially present in the parent material, hence the large difference from the elemental make up of the continental crust. On the other hand, the young soil (Iowa silt loam) still highly resembles the elemental make up of its parent material, even though it has also developed physical and mineralogical properties that are fundamentally different from those of the continental crust.

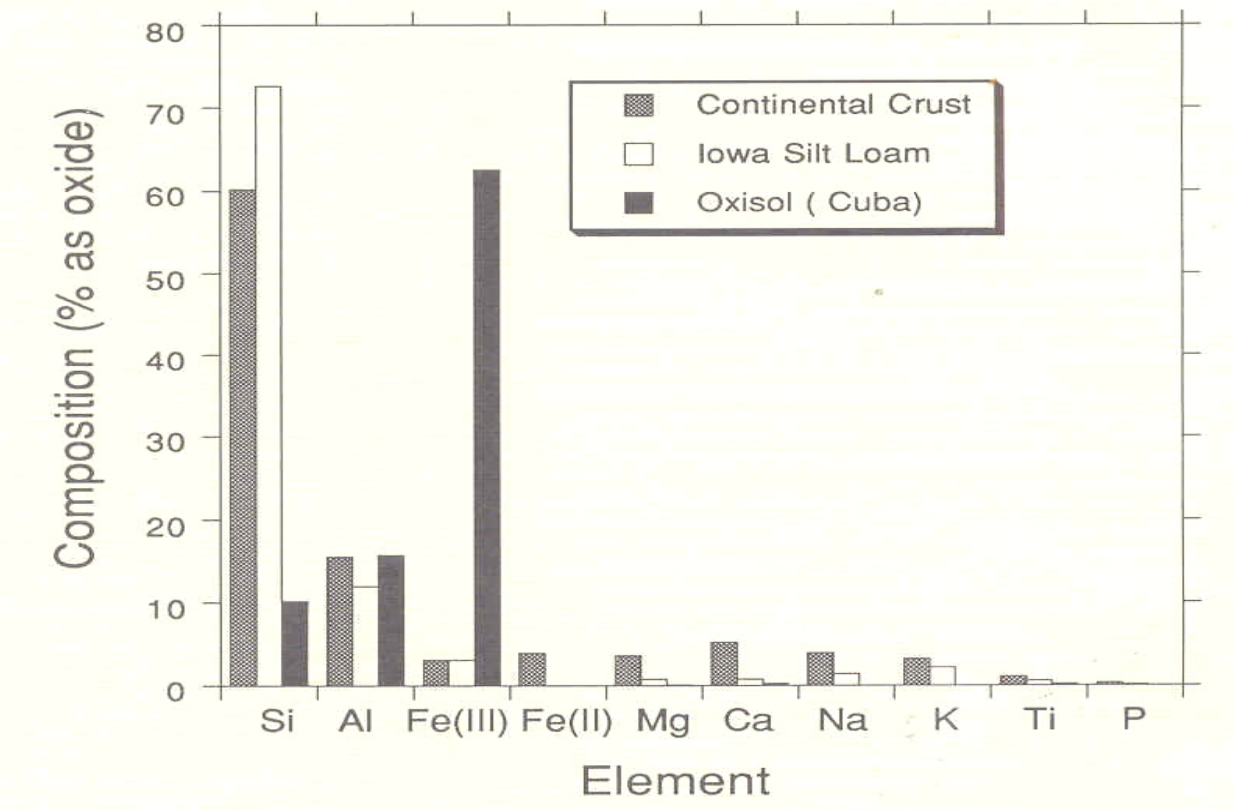

Figure 2.2 Elemental composition of an intensely weathered soil (oxisol) and a less strongly weathered soil, expressed as percent by mass of the oxide form. Also shown is the average elemental composition of the continental crust for comparison (McBride, 1994).

The nature of the parent material has been proven to have a predetermining effect on the mineralogy of both the clay fraction and the non clay fraction (Wooldridge, 1988). Minerals in soils are largely primary, i.e. mainly inherited from parent materials (Fanning & Keramidas, 1977). The distribution of different forms of K has been found to differ with soil type as a function of the dominant soil minerals present (Sharpley, 1989). Soil K is often found as an interlayer cation in micaceous minerals, which are the abundant and important micas in most soils (Fanning & Keramidas, 1977; Ross & Cline, 1984). Micas are the most important natural source of K for growing plants in most soils as they release K that becomes available for plant uptake. Micas are often present in rocks such as shales, granites, slates, phyllites, schists, gneisses and in sediments derived from these and other rocks (Fanning & Keramidas, 1977). During the weathering of micas in such rocks, interlayer K^+ is normally replaced by cations such as Mg^{2+}, Ca^{2+}, and Al^{3+}, resulting in the formation of secondary minerals such as illite, vermiculite, smectite, and interstratified minerals as shown in Figure 2.3 (Kirkman, *et al.* 1994). During weathering processes, the size of mineral particles as well as K content decrease. Potassium is depleted from about 10 % in micas to less than 1% in smectites and interlayer spacing increases from 1.0 nm (mica) to 1.4 nm (vermiculite). Under high pH conditions, i.e. abundant Ca^{2+} and Mg^{2+}, complete removal of K^+ from micas may occur, resulting in the formation of smectites. Under acidic conditions, i.e. low pH environment, vermiculites may form.

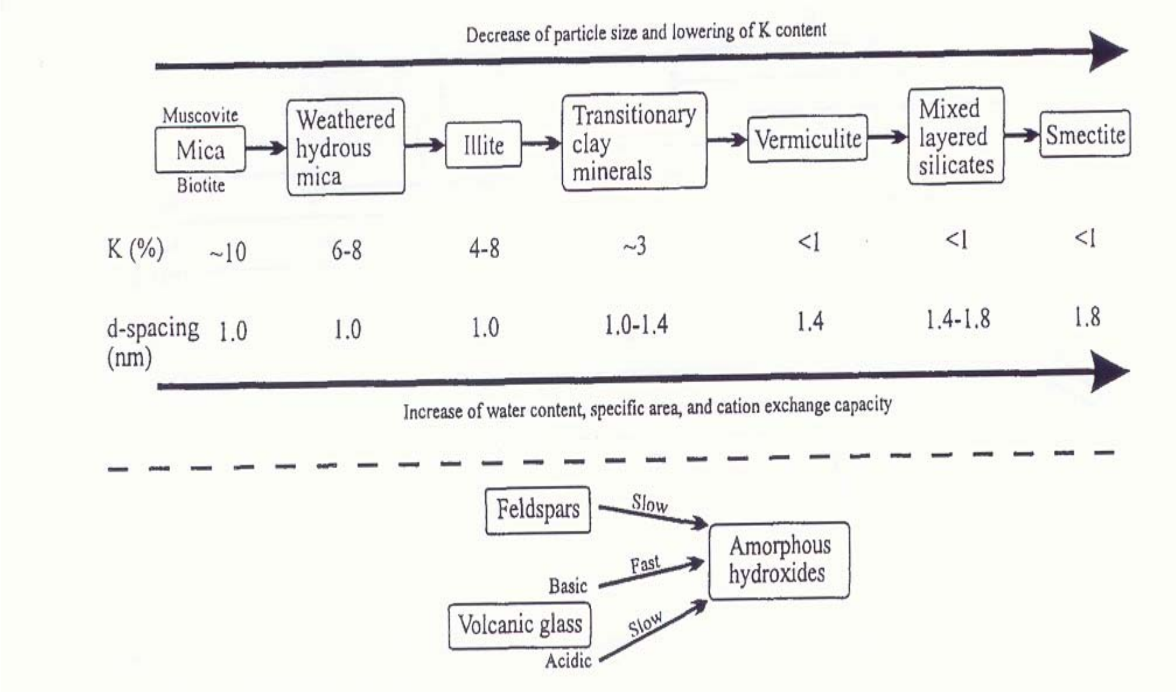

Figure 2.3 Dynamics of weathering of primary minerals (Kirkman *et al.*, 1994).

For South African soils, differing provision of K from different bedrocks (sandstone, granite and shale) with different mineral compositions have been observed (Wooldridge, 1988) and may be of significance in viticulture (Wooldridge, 2005b). Van Schoor (2001), found that soil samples with small quantities of K, reflected the presence of phyllitic shales and hornfels, whilst large quantities of soil K indicated the presence of K-rich poryphytic granites. According to White (2003), allophanic rich soils have been found with lower exchangeable levels of K than soils dominated by vermiculite or mica. Smectites rich soils are known to be responsible for high K buffering capacity, especially if present in abundance (Maji & Sen Gupta, 1982). Furthermore, exchangeable K availability was found to increase from smectitic, mixture of smectitic- kaolinitic soils, to kaolinitic soils and the capacity to supply K under continuous cropping was found greater for smectitic than for kaolinitic soils of similar exchangeable K contents for USA and Puerto Rico soils (Sharpley, 1989). Relationships between soil particle size and mineralogy are illustrated in Figure 2.4 (McBride, 1994). Secondary minerals prevail in the clay fraction whilst primary minerals are unstable in the soil environment. Once primary minerals undergo physical weathering, they are reduced to a smaller particle size and tend to chemically decompose rapidly to secondary minerals. Secondary minerals are clay sized (< 2μm in diameter) and possess a very high surface area. Moreover, along with decomposed organic matter (OM), secondary minerals can contribute substantially to the chemical reactivity of soils.

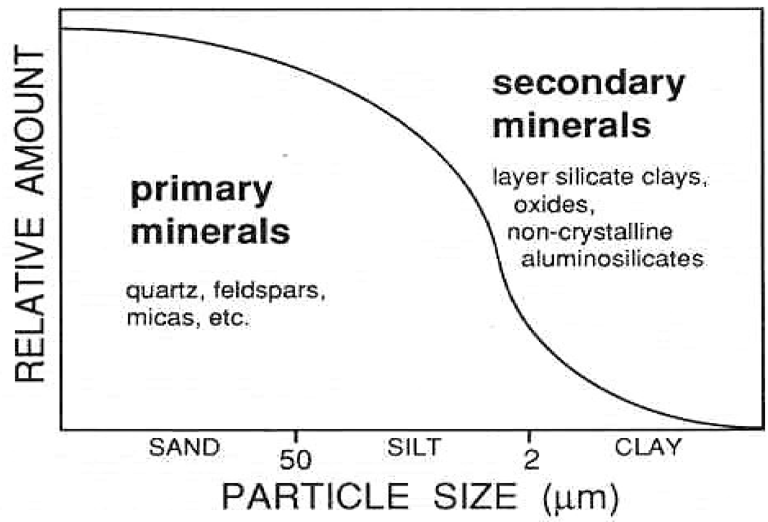

Figure 2.4 Typical presence of primary and secondary minerals in different size fractions of the soil (McBride, 1994).

Cation exchange capacity: Soil CEC has traditionally been used to index soil buffering characteristics (Wang *et al*., 2004). The ability of the clay material to retain and exchange cations on colloidal surfaces has been indicated as probably the single most important property of soils (Maltman, 2008). The type of clay, clay content and organic material content determine the CEC of the soil. In California, deep rich soils, with high CEC montmorillonite clay, many nutrients and abundant water, are known to produce vigorous growth and watery tasteless grapes (Wright, 2003), whereas the highest quality grapes are found in soils with moderate clay content, dominantly low CEC kaolinite, where the nutrients are low and water supply is at an adequate rate. Soils with a fine texture (high clay content), normally have a higher CEC and can hold a greater amount of exchangeable K. However, these soils may have a lower concentration of solution K as they have a higher buffer capacity than sandy or low clay content soils. Soils rich in montmorillonite are generally derived from impure sandstones or volcanic deposits and have high CEC values, whilst those derived from parent material such as granite are normally rich in kaolinite and have low CEC values. Organic matter (OM) is also an important source of CEC in soils (McBride, 1994) however, its affinity for K is low compared to its affinity for Ca and Mg ions.

pH: Soil pH, together with Ca and Mg, indirectly influences the availability of K, as it affects weathering of minerals, carbonate dissolution and cation exchange (White, 2003). Acidity is normally corrected in vineyard soils, but at extremes of pH, certain deficiencies or toxicities may appear (Seguin, 1986). Liming (increased pH) of acid soils may reduce solution K (Wooldridge, 1988). During liming of acidic soils, precipitation of Al $(OH)_3$ may occur, therefore leading to the availability of some previously blocked binding sites on the exchange complex, resulting in a greater amount of K being held by the clay colloids, thus reducing the amount in the soil solution. At pH (water) of less than 5, exchangeable cations (Ca^{2+}, Mg^{2+} and K^{+}) are easily displaced by cations such as Al^{3+} (White, 2003), thus inducing accelerated loss of these cations via leaching or plant uptake.

Texture and structure: Wine quality does not seem to be related to a definite textural type (Seguin, 1986). However, K availability, which contributes to wine pH levels, is affected by it (Basilo & San Valentin, 1990). Generally, soils rich in clay are likely to have a higher nutrient status than sandy soils (Maltman, 2008). Thompson (1985) found clay content highly related to K availability in some Western Cape soils. According to Mackenzie & Christy (2005), increasing clay content appeared to affect the sugar content, decreased juice pH and increased TA, possibly reflecting the water providing properties of clays. Moreover, K has been found to be a function of clay content in some soils (Sharpley, 1989). Soils with less clay, such as those derived from granite, may easily allow a loss of K, even when it is applied as a fertilizer (Wooldridge, 2000). In other studies, light textured soils have been found to be impoverished in K to such an extent that symptoms of K deficiency appeared during the first growth period (Pal *et al*., 2001). The presence of the clay material is important both as a harbour of nutrient cations and to retain water for various growth stages of the vine (Wright, 2003).

Soil structure has been reported to play a much more important role than texture; especially in the manner it affects hydrological properties of the soils (Seguin, 1986). Soils characterized by a high degree of macro porosity, tend to permit water percolation, consequently preventing stagnation at root level. Coarse soils (gravel-sand) are more permeable and well aerated than clayish soils, therefore, allowing a better root distribution and more efficient uptake of water and nutrients. Hydrological properties of limestone rich soils in the Coonawarra district of Australia were associated with good vine performance (Hancock & Hugget, 2004). Furthermore, soils that have a high clay content, especially those on compact limestone, may inhibit root penetration as the depth and the manner of root distribution have repercussions on the mineral nourishment and the water supply to the roots. Restricted root development has been associated with low yields (Myburgh *et al*., 1996). Therefore, texture and structure derived from the parent material can be accepted to affect grape composition and therefore wine style and character as they affect the water supply to the vine.

Ion antagonism: A Na-potassium (Na/K) antagonism can be shown by a decrease in K content even at low sodium chloride (NaCl) doses (Garcia & Charbaji, 1993). In certain South African vineyards, Mg and Ca uptake were found lower in the presence of high concentrations of solution K, indicating K/Mg and K/Ca antagonisms (Conradie & Saayman, 1989). In the same study, a P/K antagonism was also observed as K concentrations in both blades and petioles were reduced where there were higher levels of phosphorus.

Potassium fixation: When K concentrations in the soil increase, there is an equilibrium shift and K fixation at specific sites on clay minerals may occur (Conti *et al*., 2001). A small amount of K may be precipitated as insoluble compounds, especially as K aluminosilicates. Fixation of K may give rise to a K deficiency, although it is considered an advantage because it assists in retention and recycling of K through organic and inorganic systems and reconstitution of illitic clay minerals (Kirkman *et al*., 1994). The type of clay mineral is one major factor that determines the extent of K fixation. In general, soils containing micas, hydrous micas or vermiculites have the highest fixation capacities, whereas smectitic and kaolinitic soils have low fixation capacities. Wooldridge (2005b), reported that shale soils had the highest ability to fix K, followed by soils from sandstone and then soils from granite. The presence of kaolinite in the clay fraction, with mica and K-rich feldspar cores in the silt fraction, is believed to enable the granite soils to easily release primary K, but to have a lower ability to fix it. In contrast, the shale soil clay fractions contain vermiculite and interstratified 2:1 minerals with a higher K buffer capability.

Sandstone with sand fractions that are rich in quartz, were found to have limited buffering capabilities and with a low clay content and a low ability to release primary K.

Potassium analyses: Exchangeable K is normally extracted with a neutral salt (ammonium acetate) in order to obtain an index of the nutrient supplying power of soils. Soluble K can be used as an indication of immediately available K and can be determined in water (water extraction). Nitric acid can be used to determine non exchangeable K (HNO_3-extractable K) (Sharpley, 1989). The potassium supplying capacity of soils can also be investigated by employing the quantity-intensity (Q/I) approach introduced by Beckett (1964). In South Africa, this approach has been used to estimate the K supply of certain soils (Le Roux & Sumner, 1968; Thompson, 1985; Wooldridge, 1988). The parameters PBC^K (potential buffer capacity for K), change in K_0 (the pool of labile K) and equilibrium activity ratio ($AR^K{}_e$), derived from a Q/I plot, are used to interpret the K status of the soil. The activity ratio shows that increased levels of Ca and Mg will induce a decrease in K uptake. The activity ratio highly emphasizes the dependence of K availability on Ca and Mg and so does the BCSR (base cation saturation ratio) concept (Kopittke & Menzies, 2007). It is clear that the total quantity of K present in the soil does not directly determine how much K will be available for uptake. Other cations, especially Ca and Mg need to be considered as well.

2.4.3 Viticultural aspects

Despite soil conditions, the absorption of K highly depends on the plant (scion and cultivar, water and nutritional status) and once K is absorbed, its accumulation in the grape berry depends on other grapevine related factors.

Rootstocks, scion and rootstock/scion combination: Generally, crops differ in their ability to extract K^+ from the soil solution (Kirkman *et al*., 1994) and in certain cases, grapevines may take up more K from the soils than N and P (Tsitsilashvili, 1976). Cation nutrition has been found to vary as a function of the rootstock (Garcia *et al*., 2001). Considerable research has been carried out with the aim of reducing K in the fruit. It has been observed that rootstocks can affect grape juice pH by changing grape juice K^+ concentration (Rühl, 1992). The mechanisms responsible for the different K accumulation rates by shoots are suggested to be located in the roots (May, 1994). Garcia *et al*. (2001) found that cation nutrition varied as a function of rootstock. Various rootstocks have different resistance thresholds for some elements (Garcia & Charbaji, 1993). The rootstock, 3309, appeared to be the most appropriate rootstock in order to decrease the absorption of K from the soil, in comparison to SO4 and 101-14 Mgt. Furthermore, the rootstock-scion combination affects grape berry composition (Downton, 1977), and the nature and magnitude of the effect varies (Walker *et al*., 1998). Pinton *et al*. (1990) showed that different cultivars had significantly different rates of (^{86}Rb) K^+ uptake, whilst the high K storage property of the cultivar Négrette was associated with low acidity of the wines (Garcia *et al*., 1999).

Canopy density and canopy management: Shading in the canopy is a direct effect of a vigorously growing vine, which is characterized by a dense canopy. Canopy shading is one of the most important factors affecting berry K accumulation as it limits photosynthesis through affecting the micro climate of the vine (Iland, 1989). High canopy densities cause shading, which is associated with higher grape juice K, pH and malic acid content (Smart *et al*., 1990). Shaded leaves transport more K than exposed leaves to the berries (Iland, 1988). The mechanism for such transfer of K is related to the senescence process, when it is hastened by any cultural activity that reduces photosynthesis, i.e. shading, lack of water and/ or nutrients and pests (Wood & Parish, 2003). Increased vine vigour or crop production may enhance K^+ uptake and translocation as it causes an increasing demand for K (Wood & Parish, 2003). To limit K movement to the berry, the vine leaf should be an efficient photosynthetic unit and this is enhanced when canopy management is applied (Hunter, 2000). Canopy management includes the alteration of the position or density of leaves, shoots and fruit in order to achieve a desired arrangement (Smart *et al*., 1990). Efficient canopy management may positively affect translocation and accumulation of assimilates in berries.

Canopy management is normally applied in conditions where there are high shoot numbers and high vine vigour, which may result in high canopy density and consequently in an increased degree of shading within the canopy. A high canopy density is known to be associated with a high juice pH, but not in all cases (Engelbrecht & Saayman, 2005). On the other hand, open canopies are known to lead to improved berry composition and are associated with lower malate and K concentrations in the pulp (Iland, 1988). Proper management of the number of leaf layers, in order to ensure maximum photosynthesis on the inside of the canopy, is needed.

Fertilisation: It is commonly believed that fertilizing vines with K will contribute to high K levels in the fruit, even though there is no direct route from the soil to the fruit but a carefully controlled pathway (Wood & Parish, 2003). Potassium addition in a fertilizer form has been reported to affect grapevine and berry composition, but not in all cases. Rühl (1989) reported that higher K fertilization increased grape juice pH, malate concentration and K concentration. Moreover, Conradie & Saayman (1989), reported significant increases in K levels of blades, petioles and musts in response to K-fertilization, in comparison to where no K was applied. In contrast, Engelbrecht & Saayman (2005) found that Ca and Mg fertilisation had no significant effect on the juice and wine K content but had an effect on the juice pH, even though this effect was not carried through to the wine pH. Affecting the K and/or pH of must through the manipulation of soil K via K fertilization, is difficult when vines are adequately supplied with K (Conradie & Saayman, 1989). Therefore, K uptake will be independent of K content of the soil, unless deficiency levels exist (Boulton, 1980b). Furthermore, according to Mpelasoka *et al*. (2003), many factors may affect the impact of K fertilizer on the level of plant available soil K, for example, the amount and type of fertilizer applied, the timing and frequency of application, soil characteristics and management, the amount and frequency of irrigation, plant root activity and initial vine nutrient status.

2.5 SUMMARY

Potassium takes part in various important processes in grapevines. Deficiencies may have consequences that may hamper proper functioning of the whole plant whilst excess may negatively affect acid balance in grape juice, pH and wine quality. There are climatic factors that affect the photosynthetic ability of the grapevine and stomatal behaviour in turn also affect K accumulation and malate concentrations in the berries. The type of clay mineral and clay content are the dominant factors that may determine the extent of K^+ fixation and release. The type of clay mineral is largely determined by type of parent material (geology). Soil moisture, temperature, pH, Ca and Mg contents, cation exchange capacity and particle size, also contribute to the availability of soil K as not all the K in the soil is available for uptake. Furthermore, the rootstock, cultivar and rootstock/ scion combination also have an influence on how much K is taken up. The nutrient and water status of the grapevine and its canopy density can further affect the distribution of K within the grapevine. The role of geology in the soil K status is understood. However, the relationship between soil K and grapevine K is not yet clear, as there are certain soil, viticulture and climate factors that contribute to the vineyard K status.

Soil developed from a specific parent rock material and changes that do occur during physical and chemical weathering alter the final composition of the soil. The resulting soil normally does not closely reflect the original parent material, especially in terms of mineralogy and elemental composition due to intensive weathering processes and soil processes such as colluviation. Moreover, geology affects the nature of particle size which determines water regulation in the soil. However, compared to geology and soil properties, viticulture (canopy density, vine water status) and climate factors (temperature, wind and humidity) may play a bigger role in terms of K distribution in the vine.

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Chapter 3

Research results

Nutritional status of geologically different vineyard soils

CHAPTER 3: RESEARCH RESULTS

3.1 ABSTRACT

Little scientific information regarding the effect of different geological parent materials on grape juice composition is currently available in South Africa. This aspect is of special significance for the Helderberg area, where parent material may change from granite to shale over a short distance, resulting in shale-derived as well as granite-derived soils often occurring within the same vineyard. The objective of this study was to quantify the nutritional status and other soil properties of different parent materials (shale and granite) and overlying soils. The study was done over two seasons (2006/2007 and 2007/2008). Soil samples were taken adjacent to vines at three horizons. Chemical analyses, including exchangeable cations, soluble K, and total K were determined. Quantity-intensity (Q/I) relationships for K were studied for certain top soils. Clay mineralogical composition and particle size analyses were also performed. Soil water content was monitored throughout the seasons.

Kaolinite was the dominant mineral, whereas quartz and feldspar were sub-dominant. Traces of mica were also present in some shale- and granite-derived soils. Granite derived soils contained significantly higher amounts of coarse sand than shale-derived soils, whilst the opposite was found for fine sand. These differences affected the water holding capacity, in general making it higher in the shale- than in granite-derived soils. Shale-derived soils had higher concentrations of total K but granite-derived soils had a higher ability to release K as they contained higher concentrations of soluble K. The Q/I parameters, potential buffering capacity for K (PBC^K) and equilibrium activity ratio for K (AR^K) showed no consistent relationships with geological differences. These soils had been exposed to intensive weathering and high rain fall. Furthermore, both granite- and shale-derived soils at each vineyard received similar soil preparation and amount of water. All these conditions and practices were suggested to have negated the effect of geology on the nutritional status of these soils, thus making it difficult to quantify the differences between granite- and shale-derived soils.

Keywords: Geology, granite, shale, potassium

3.2 INTRODUCTION

In viticulture the concept of terroir acknowledges soil, topography and meso-climatic effects on vine growth and wine quality. The effects of climate on grape composition and wine character are indisputable (Conradie *et al*., 2002). In warm regions, soil has been suggested to play a subordinate role to climate (Rankine *et al*., 1971). However, in South Africa, soil may have a more important role to play. The characteristics of Cinsaut wines varied according to the soil type on which the vines were grown, even when meso-climatic conditions were similar (Saayman, 1977). More complicated than soil are the effects of geology (parent material) on grapevine composition. Parent materials, clay mineralogy, as well as soil forming processes, lead to the formation of soils with specific, definable characteristics (McBride, 1994). According to Wilson (1998), geology may have a predetermining effect on wine quality and character. In some European countries, different parent materials are increasingly being used to grow wine grapes (White, 2003). The nutrient status of the soil is widely believed to be related to the parent material (especially its mineralogical composition) that soil has been derived from. A large percentage of vineyard soils in the Western Cape is derived from granite, shale or sandstone (Conradie *et al*., 2002, Bargmann, 2005). In South Africa, it has been observed that granite-derived soils of the Western Cape are relatively rich in potassium (K) (Wooldridge, 1988), whereas soils originating from phyllitic shales may have the lowest K levels in comparison to other soils, including granitic soils (Conradie *et al*., 2002). Granite-derived soils were found to have a low buffering capacity for K, as Italian rye grass grown on such soils showed a luxurious consumption of K, whilst shale-derived soils were able to retain and release their K in an adequate manner (Wooldridge, 1988). According to Wooldridge (2005), luxurious consumption of K may also occur in vineyards planted on granite rich soils. Van Schoor (2001) found it difficult to relate parent material directly to grapevine growth. According to Conradie *et al*. (2002), vineyard practices such as soil preparation and fertilisation may make it difficult to study the impact of geology in vineyard performance. Potassium and nitrogen (N) are elements that may have a significant effect on wine quality, especially if no serious deficiencies of other essential elements exist (Saayman, 1992). Soil K levels may have a substantial effect on the acid balance of the grape juice and, therefore, wine pH (Conradie & Saayman, 1989). However, there are other factors in the soil that affect the response of grapevines to soil K, e.g. clay content, K saturation of the exchange complex and K/Mg ratios (Conradie *et al.,* 2002). Thompson (1985) evaluated some Western Cape soils and found that soils with higher clay contents are well supplied with K and had enough K available for plant uptake.

In one of the wine growing areas, in the Western Cape, Helderberg, parent material may change from granite to shale over a short distance, resulting in shale-derived as well as granite-derived soils often occurring within the same vineyard. Therefore, this study investigates the soil nutritional status in geologically different vineyards in the Helderberg area, with the aim of exposing the effect of geology on the nutritional status of soils while also quantifying the K supply of the granite- and shale-derived soils.

3.3 MATERIALS AND METHODS

3.3.1 Vineyards

The field investigation was conducted over two seasons (2006/2007 and 2007/2008) in the Helderberg area (South Western Cape region, South Africa) at four different farms. Four commercial vineyards (2 x Sauvignon blanc and 2 x Cabernet Sauvignon), designated as experimental plots S1, S2 for Sauvignon blanc and C1, C2 for Cabernet Sauvignon (Figure 3.1), were selected at altitudes of 400 m, 232 m, 227 m and 288 m, respectively. Before the vines were planted, general cultivation practices, which includes delve ploughing to a depth of approximately 800 mm and addition of lime with the aim of increasing soil pH (KCl) to at least 5.5, were done (Conradie *et al*., 2002). After planting, N, K and P are normally applied according to production (Conradie *et al*., 2002). All the experimental sites were drip irrigated, with the exception of C2, which was rain-fed.

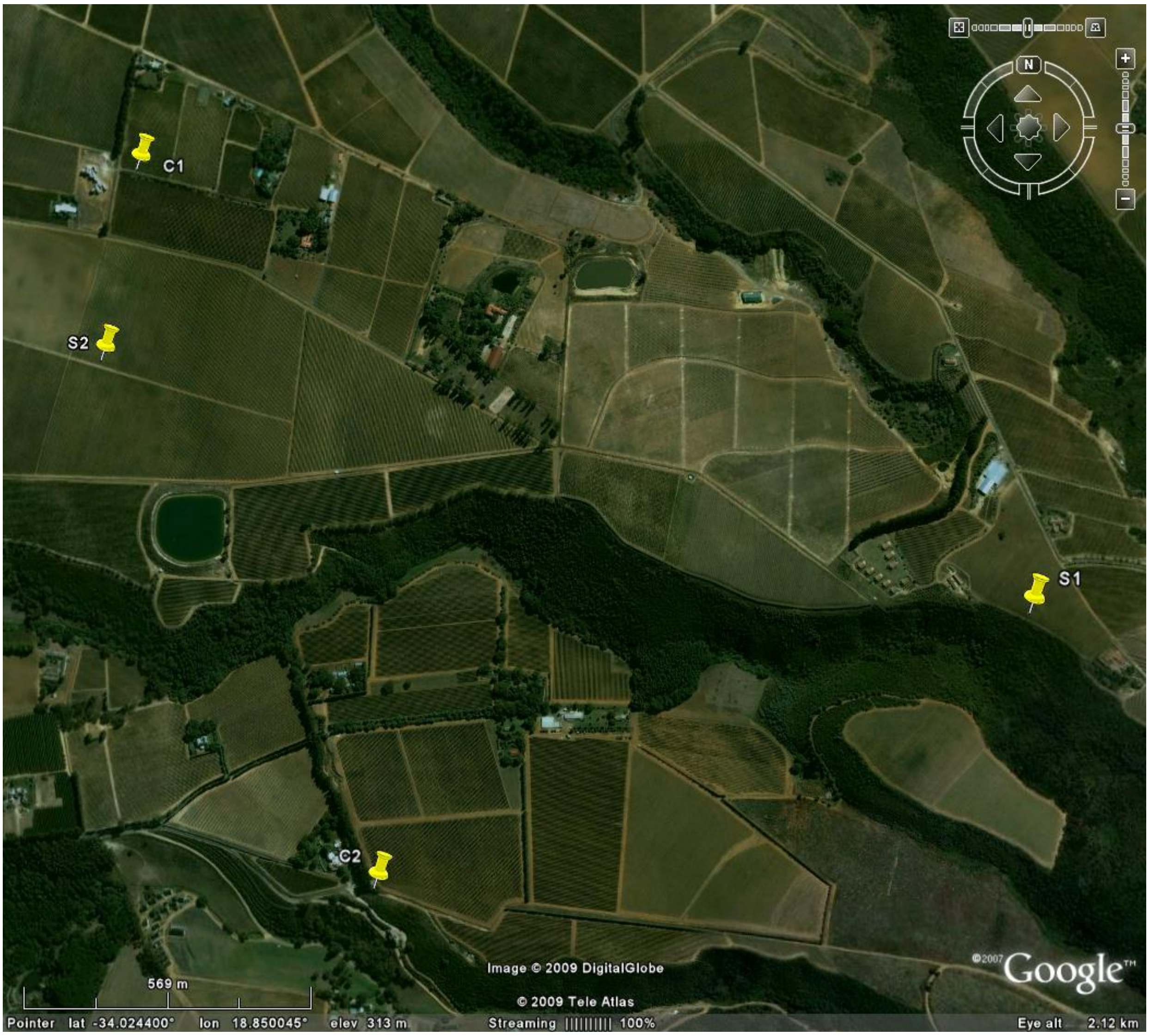

Figure 3.1 Sauvignon blanc (S1 & S2) and Cabernet Sauvignon (C1 & C2) experimental vineyards in Helderberg.

3.3.2 Experiment layout

Within each experimental vineyard, plots on shale- and granite-derived soils were established. Six opposing experimental vines per plot were selected from two adjacent rows (three vines per row).

3.3.3 Data collection and analyses

Soil sampling and analyses

A soil profile pit of 2 x 3 m dimension and 1.5 m deep was used and the soil described according to the South African soil classification system (Soil Classification Working Group, 1991). Soil samples were taken directly opposite each experimental vine in all the plots. At each plot, a soil auger was used to obtain 6 top soil A horizon, 6 subsoil B1 horizon and 6 subsoil B2 horizon samples. Thereafter, the samples were air dried and sieved through a 2 mm sieve. Soil samples were thereafter analyzed for pH (1:5 water), K, Ca, Mg and Na (all extracted with 1 M NH_4OAc), soluble K and NO_3-N (1:5 water), total K and P (Bray No. 2 extract: 0.03 M NH_4F in 0.01 M HCl), CEC (with 1 M NH_4Cl at pH 7) and organic C by the Walkley Black procedure (Soil

Classification Working Group, 1991). A pipette method explained by Gee & Bauder (1986) was used for the determination of particle size. Clay mineralogical composition was investigated by x-ray diffractometry after preparation of KCl/MgCl saturated soil paste slides according to Whittig & Allardice (1986).

In order to investigate the ability of these soils to supply K, quantity/intensity (Q/I) relationships for K were studied. Since the experiment required each sample to be replicated 8 times, a decision only to study a few samples as a start was taken. Consequently, two farms (C1 and C2) were used and only five samples (A-horizons) per soil type were selected, resulting in twenty samples in total. Potassium Q/I isotherms were constructed according to a procedure used initially by Beckett (1964), with some modifications described by Thompson (1985). Soil samples of 5 g were placed in eight 100 cm^3 containers with 50 cm^3 of 0.001 M $CaCl_2$ and with K concentrations of respectively 0, 5.8, 11.5, 21.0, 31.5, 42.0, 52.5 and 63.0 mg kg^{-1}. To obtain enough data points on K release, 0.5 g and 2.5 g soil samples were also mixed with 50 ml of 0.001 M $CaCl_2$ but with no addition of K. These isotherm experiments were conducted at ± 21 ^{0}C. The prepared soil suspensions were shaken for an hour and left to stand undisturbed for 14 hrs thereafter, centrifuged and filtered. The concentrations (K, Na, Mg and Ca) in supernatant solutions were determined by inductive coupled plasma (ICP) procedures. The final exchangeable K (EK_f) for each equilibrium point was calculated based on NH_4OAc extraction. The change of K (ΔK) in the solution was measured as follows: $\Delta K = (CK_i - CK_f)$ (v/w), where ΔK is the change of K in solution, CK_i is the concentration of added K in solution, and CK_f is the final equilibrium concentration of K in solution ($CaCl_2$ extracted). Potassium activity ratio (AR^K) was used to describe the intensity of K in the presence of Ca and Mg as follows (Becket, 1964): $AR^K = CK_f / (Ca_f + Mg_f)^{1/2}$, where Ca_f and Mg_f are activities of Ca and Mg in final equilibrium solutions, respectively. Regression analysis was done in MS Excel software. Out of the 20 samples, five did not give satisfactory results and were discarded from the data set. Overall, the results obtained were not very useful for this study; hence the decision not to work on the rest of the samples was made.

To monitor soil water content, access tubes (one tube per experimental plot) were inserted at each granite- and shale-derived soil site at all localities (close to where the soil samples were taken). Soil water content was measured using a neutron probe meter which was calibrated for each specific soil. Neutron counts reflective of soil water at 0-300 mm, 300-600 mm and 600-900 mm were converted to soil water content values. Furthermore, water holding capacity was calculated as the difference between soil water content at field capacity (-10 kPa) and permanent wilting point (-1500 kPa).

Statistical analyses

Analysis of variance was performed on all variables using the general linear models (GLM) procedure of SAS statistical software version 9.1 (SAS, 2000). The Shapiro-Wilk test was performed to test for normality (Shapiro & Wilk, 1965). Student's t-least significant difference was calculated at the 5 % and 10 % levels to compare treatment means (Snedecor & Cochran, 1980). Where data could not be analyzed statistically due to a smaller sample number per plot, means were used to compare between treatments.

3.4 RESULTS AND DISCUSSION

3.4.1 Soil forms, particle size composition and clay mineralogy

Soil forms and descriptions for both granite- and shale-derived soils are indicated in Table 3.1. Similar soil forms were identified at S1, S2 and C2, despite the differences in geological formations. However, at C1 two contrasting soil forms were identified. Fairly large differences may occur within a soil form as classification of soils into soil forms is the first category, thereafter further classification into families (based on A, B and E horizon properties, degree of leaching, clay movement and wetness) follows (Soil Classification Working Group, 1991).

Table 3.1 Characteristics of viticulture soils from geological different vineyards (S1, S2, C1 and C2) in the Helderberg area.

Experimental vineyard	Soil form		Description	
	Granite	Shale	Granite	Shale
S1	Tukulu	Tukulu	Yellow brown, luvic, medium texture, favourable structure with signs of wetness in the subsoil.	Yellow brown, luvic, medium texture, favourable structure with signs of wetness in the subsoil.
S2	Tukulu	Tukulu	Yellow brown, luvic, medium texture, favourable structure with signs of wetness in highly weathered rock subsoil.	Reddish brown, luvic, medium texture, favourable structure with signs of wetness in highly weathered rock subsoil.
C1	Pinedene	Oakleaf	Light textured, luvic, yellow brown apedal B horizon, favourable structure with signs of wetness in heavier textured subsoil.	Reddish brown, not luvic, favourable structure, well drained with no signs of wetness in the subsoil.
C2	Tukulu	Tukulu	Yellow brown, luvic, medium texture, favourable structure with signs of wetness in highly weathered rock subsoil.	Yellow brown, luvic, medium texture, favourable structure with signs of wetness in highly weathered rock subsoil.

Further distinctions that are associated with differences in parent materials were observed in the physical composition of soils, especially sand particle size. Figure 3.2a illustrates that shale-derived soils contained a significantly higher content of fine sand than the granite-derived soils. On the other hand, figure 3.2b shows that granite-derived soils (both B-horizons) contained a higher content of coarse sand than the shale-derived soils. These findings were in agreement with those of Van Schoor (2001) and Conradie *et al*. (2002). Furthermore, according to Theron *et al*. (1992), coarser fragments are normally expected in granite-derived soils. The differences in particle size between soils in the A-horizons were not as large as those observed in the B-horizons. This indicated that soils in the A-horizons were more mixed with colluvium during weathering (White, 2003) and thus not able to reflect the geological differences as well as the B2 saprolite rich horizons (Ollier & Pain, 1996). On account of differing fine and coarse sand fractions, especially in the B horizons, it was confirmed that parent materials were of granite and shale origin.

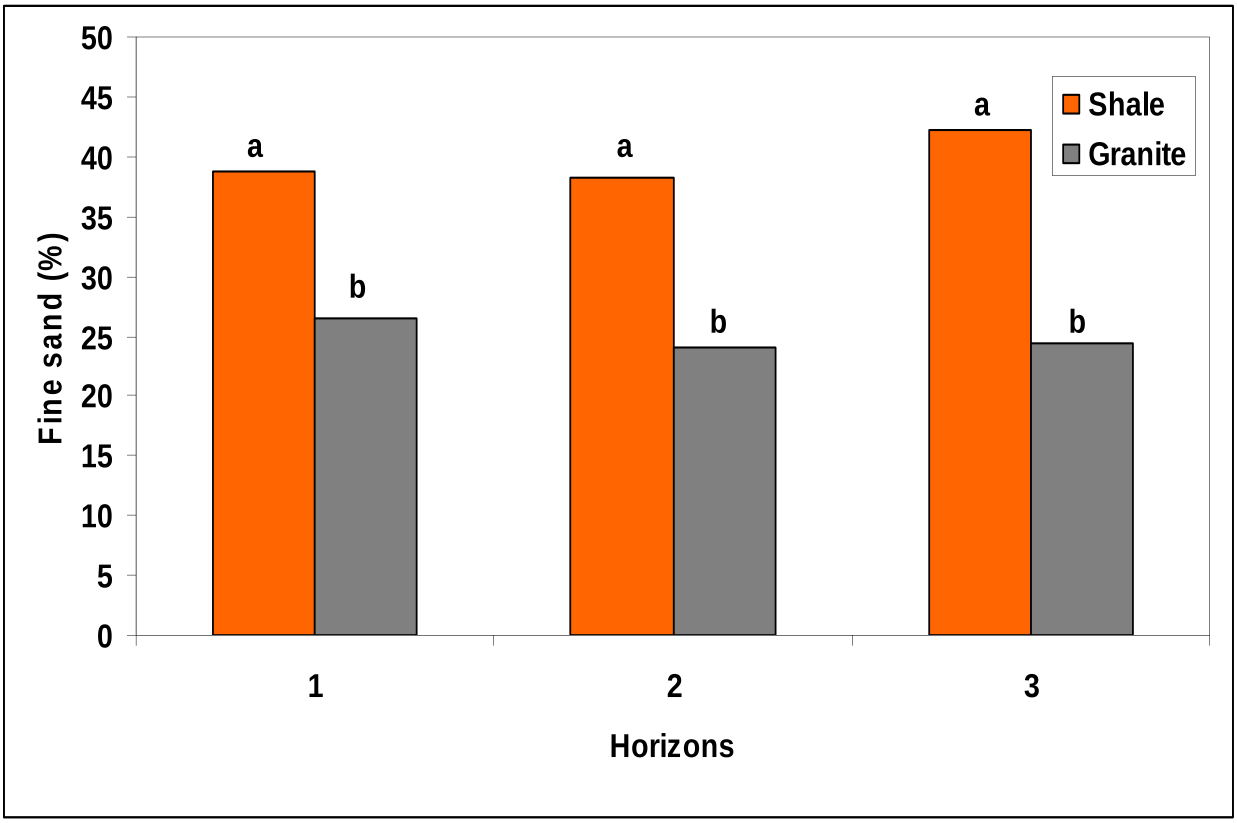

Figure 3.2a Fine sand content of granite and shale-derived soils at four localities in the Helderberg area (values with different letters indicate differences, P ≤ 0.1, values 1, 2 and 3 represent horizons A, B1 and B2, respectively).

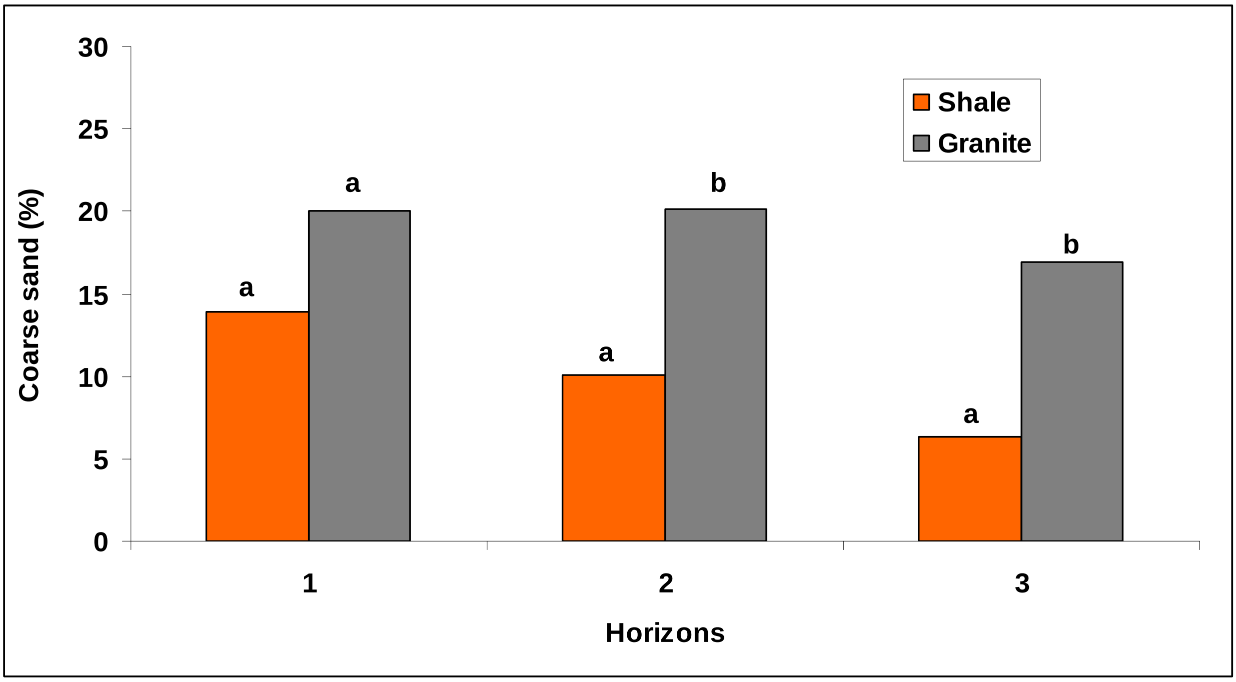

Figure 3.2b Coarse sand content of granite and shale-derived soils at four localities in the Helderberg area (values with different letters indicate differences, P ≤ 0.1, values 1, 2 and 3 represent horizons A, B1 and B2, respectively).

Both granite- and shale-derived soils were characterised by clay contents that were typical of Western Cape soils but insignificant differences in clay contents were observed between the two soils (Appendix 3A, Table 3.1). Some Western Cape soils, studied by Thompson (1985) were characterised by high clay contents and were well supplied with K which was adequate for plant uptake. Furthermore, according to Conradie *et al*. (1996), clayey soils of the Western Cape tend to contain large reservoirs of K, which may be problematic for vineyards. However, for these soils the clay contents were not very high (Appendix 3A, Table 3.1), therefore K levels were not expected to be problematic in these vineyards (further discussed in section 3.4.2).

Intensity peaks from the x-ray diffraction analyses of the soils showed that kaolinite was the dominant mineral, whereas quartz and feldspar were sub-dominant in both shale- and granite-derived soils. Relative abundance of kaolinite in the Western Cape soils have been reported by Wooldridge (1988), Van Schoor (2001), Bühmann *et al*. (2004) and Agenbach (2006). Kaolinite and quartz are weathering products that are usually found in soils that have reached an advanced stage of weathering (Nortcliff, 1988). Furthermore, kaolinite may have been neoformed from chlorite (Bühmann *et al*., 2004). The presence in the apparently shale-derived soil of feldspar, which is a major component of granite, implies mixing of parent materials. The presence of quartz was attributed to its ability to resist decomposition in soils during weathering (McBride, 1994). In addition, small quantities of mica were found in certain soils, but few, if any, weathered micaceous structures (e.g. vermiculite, chlorite or interstratified 2:1 silicates). According to Bühmann *et al*. (2004), the rate at which mica disappears during weathering increases with rainfall. Furthermore, the incidence of mica is low in soils with exchangeable K percentages below 5.

At S1, intensity peaks for feldspar and kaolinite were stronger in the granite- (Fig. 3.3a), than in the shale-derived A and B1 horizons (Fig. 3.3b). Peaks for quartz and mica were poorly represented. A similar pattern was shown at S2, except that mica was absent (Appendix 3A, Figs. 3.1a & b). At C1, quartz was detected only in the A horizons, and its intensity peaks were stronger in the granite- than the shale-derived soils, as expected (Appendix 3A, Figs. 3.1c & d). Peaks for kaolinite and feldspar were minimally defined in the A horizons but were better defined in the lower horizons, particularly in the granite-derived B horizons. At C2, peaks for only two minerals, kaolinite and feldspar, were observed in the clay fraction of the granite-derived soil (Appendix 3A, Fig. 3.1e). Peak heights tended to increase slightly with depth. In the shale-derived soil peaks were subdued, notably in the A horizon where only kaolinite and feldspar were represented (Appendix 3A, Fig. 3.1f). Peaks representing kaolinite, feldspar and quartz were nevertheless apparent in both B horizons of the shale-derived soils.

Collectively, the mineralogical compositions indicate that these soils are highly weathered, probably due to high temperature and rainfall during a previous geological period. This would have caused leaching of cations, notably potassium. Because differences in mineralogical composition are now small, evidently reflecting the convergent effects of long protracted weathering on soil mineralogy, these soils are expected to show very similar chemical and physical characteristics per unit clay content.

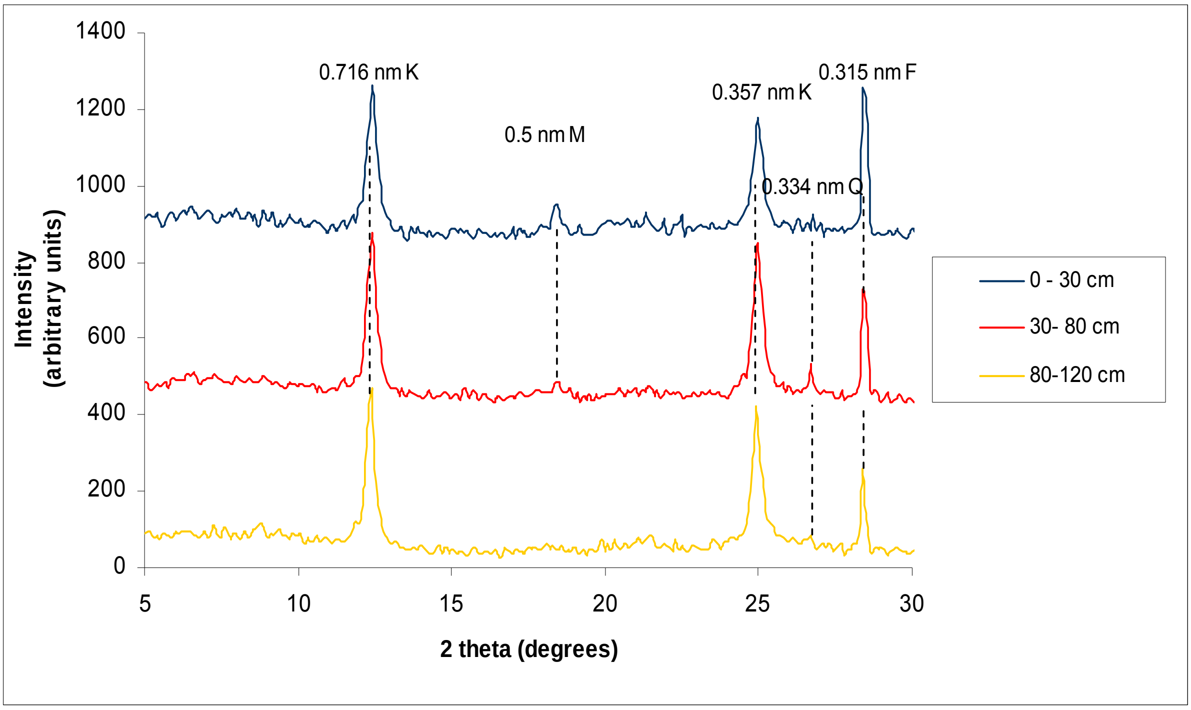

Figure 3.3a A clay diffraction pattern of a granite-derived soil from locality S1 in Helderberg (F = feldspar, Q = quartz, K = kaolinite and M = mica).

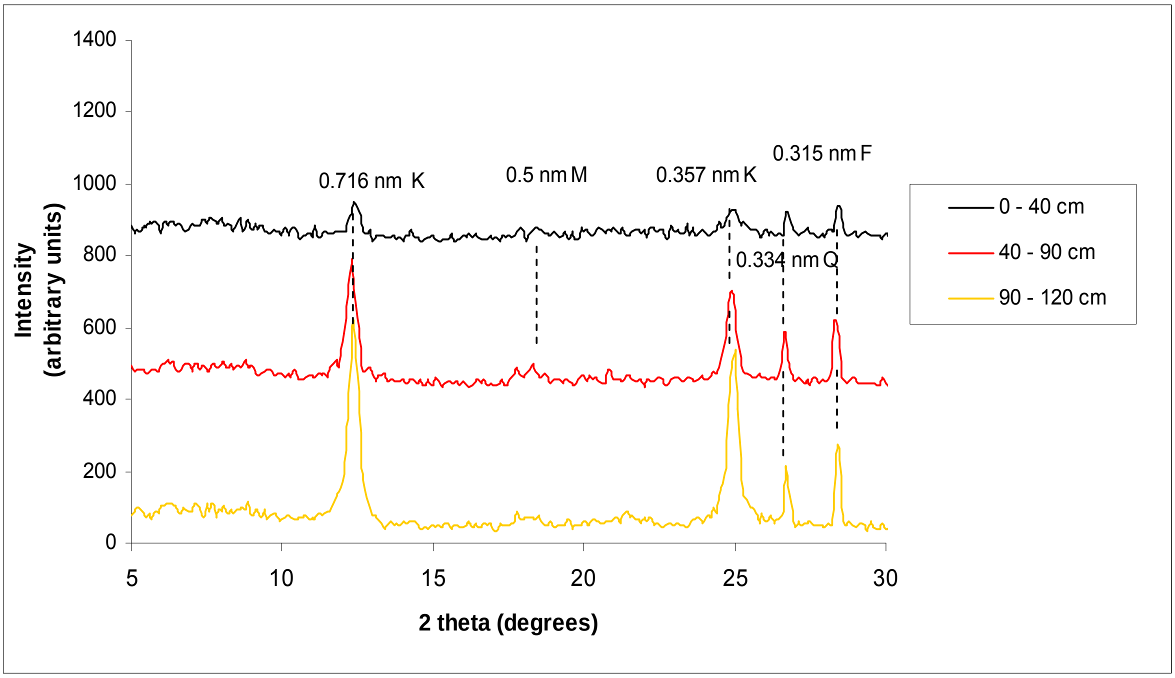

Figure 3.3b A clay diffraction pattern of a shale-derived soil from locality S1 in Helderberg (F = feldspar, Q = quartz, K = kaolinite and M = mica).

3.4.2 Different forms of soil K

Both granite- and shale-derived soils were found with similar exchangeable K levels per horizon (Table 3.2). These findings contradicted those of Wooldridge (1988) who found shale soils from the Western Cape with less K than granite soils. Mixing of parent materials (granite, shale and sandstone) during weathering and soil preparation before planting may have contributed to diminishing chemical differences due to parent material. Fertilisation has been reported to contribute in altering chemical differences due to parent material (Conradie *et al*., 2002). The A-horizons were found with high levels of exchangeable K, which were greater than the norms for the Stellenbosch area (near Helderberg) i.e. 70-80 mg kg $^{-1}$ (0.18-0.20 cmol$_c$ kg^{-1}) (Conradie, 1994). These high levels of K in the A-horizons were due to fertilisation. Although slightly lower than the levels in the A-horizons, the B1-horizon soils also had high K levels (Table 3.2). Besides that during soil preparation K can be adjusted to a depth of 600 mm, leaching of K into the B1- horizons may also have resulted in the high K levels observed. The K levels in the B2-horizons were low and indicated that these soils had experienced a high degree of weathering which may have diminished differences due to parent material as K concentrations decrease with time (McBride, 1994).

Table 3.2 Concentrations of different forms of K in granite and shale soils in Helderberg.

Horizons	Exchangeable K (cmol$_c$ kg^{-1})		Soluble K (mg ℓ$^{-1}$)		Total K (mg kg^{-1})	
	Granite	Shale	Granite	Shale	Granite	Shale
A	0.43 a	0.48 a	5.93 a	6.07 a	550 a	752 b
B1	0.27 a	0.23 a	3.79 a	2.73 a	466 a	644 b
B2	0.17 a	0.15 a	2.26 a	1.90 a	368 a	484 a

Values in the same row with different letters indicate differences ($P \leq 0.05$ for exchangeable and soluble K and $P \leq 0.1$ for total K).

Soluble K in the B horizons of granite-derived soils tended to be higher than that of the shale-derived soils (Table 3.2). Wooldridge (1988) found that Western Cape granite soils had a higher ability to release K than shale-derived soils. However, total K was higher in horizons (A and B1) of shale- than granite-derived soils (Table 3.2). This may imply that with time, shale-derived soils may have a higher potential to supply K than granite-derived soils.

Statistical differences due to geological differences could not be analyzed for individual localities, due to a smaller sample number than that required for statistical analyses. However, in order to compare treatments, mean values per soil type per individual locality were calculated for exchangeable, soluble and total K (Appendix 3B, Table 3.1a). Exchangeable K tended to be higher in the granite- than the shale-derived soils at localities S1 and C2. In general, soluble K tended to be higher in granite- than shale-derived soils, whilst the opposite was found in terms of total K. Comparison between localities showed that exchangeable K was highest for S2, but similar in the other experimental sites (Appendix 3B, Table 3.1b). The different localities imply different fertilisation practices which may be the reason for the higher K values in S2. The K results in this study are in agreement with the conclusions of Conradie *et al*. (2002), i.e. K levels of B-horizons can generally not be related to underlying geological formations. Management practices and mixing of parent material may have altered the soils, thus masking its original geological characteristics.

3.4.3 Soil chemical properties

No significant differences were observed in terms of pH, exchangeable cations (Ca, Mg and Na), P and CEC between shale- and granite-derived soils in all the horizons, when all the soils from all the localities were combined (Table 3.3a). None of the horizons had excessively low or high pH values; lime was obviously adequately mixed during soil preparation. The B-horizons of locality S2 were found to have the lowest pH values when localities were compared (Appendix 3C, Table 3.1a), mainly on account of lower pH values from the granite-derived soils at this locality (Appendix 3C, Table 3.1b). Lower pH values at S2 especially in granite-derived soils may suggest that the differences in particle size i.e. granite-derived soils having a higher coarse sand content than shale-derived soils may have induced more leaching of Ca in granite-than shale-derived soils. According to Conradie (1994), at pH (KCl) values of 5.0 to 5.5, or pH (H_2O) 6.0 to 6.5, grapevine performance should not be seriously impeded.

Table 3.3a Some chemical properties of granite and shale soils in Helderberg.

Soil property	Profile horizons					
	A		B1		B2	
	Granite	Shale	Granite	Shale	Granite	Shale
pH (H_20)	6.34 a	6.27 a	6.22 a	6.25 a	6.07 a	6.16 a
$Ca_{ex.}$ ($cmol_c\,kg^{-1}$)	5.00 a	5.06 a	2.53 a	2.76 a	1.67 a	1.91 a
$Mg_{ex.}$ ($cmol_c\,kg^{-1}$)	1.10 a	0.98 a	0.69 a	0.49 a	0.80 a	0.54 a
$Na_{ex.}$ ($cmol_c\,kg^{-1}$)	0.05 a	0.05 a	0.04 a	0.05 a	0.0 3 a	0.04 a
P (mg kg^{-1})	20.0 a	29.3 a	3.25 a	2.25 a	1.50 a	1.25 a
CEC ($cmol_c\,kg^{-1}$)	6.10 a	6.76 a	5.37 a	5.74 a	4.80 a	5.01 a

Ca_{ex}., Mg_{ex}., $Na_{ex.}$, P and CEC represent, exchangeable Ca, exchangeable Mg, exchangeable Na, phosphorus and cation exchange capacity, respectively.

Values in the same row with different letters indicate differences ($P \leq 0.05$).

Calcium levels (Appendix 3C, Table 3.2a) did not reflect pH values in Appendix 3C, Table 3.1a when localities were compared. However, when the effect of geology per locality was evaluated, Ca levels of granite-derived soils at S2 (Appendix 3C, Table 3.2b) corresponded with low pH values (Appendix 3C, Table 3.1a) at this site. As mentioned above, leaching of Ca may have been higher in granite- than in shale-derived soils. In addition, Van Schoor (2001) found that porphritic granite rocks (dominant in the Coastal wine region) contained lower Ca levels in comparison to Malmesbury shales and hornfels.

The A-horizons were found with the highest amount of phosphorus (Table 3.3a), probably due to P-fertilisation, as P content of parent materials of the Western Cape soils tends to be low (Visser, 1964). For grapevine cultivation, deficiencies or ion antagonisms (i.e. P/K) were not expected to occur at these concentrations (Conradie & Saayman, 1989). The very low P levels in both B-horizons indicated improper mixing of P into subsoils. Furthermore, there could not be any leaching of this element from the A- into the B-horizons due to the immobility characteristics of P in soils.

All the soils were highly leached and were characterized by low CEC values (Table 3.3a), which is typical of soils from the coastal regions of South Africa (Conradie, 1981). The highest CEC was found at S2 and mainly on account of higher values from the B2 shale-derived soil (Appendix 3C, Table 3.3a). The B-horizons were expected to resemble the characteristics of the parent rock more than the upper horizons. The B2-horizons at S1 showed that soil derived from granite had a higher CEC than that derived from shale (Appendix 3C, Table 3.3b). Observations at S2 agreed with the findings of Conradie *et al*. (2002) in terms of shale-derived soil obtaining high CEC values. Although not observed in the mineralogy results (section 3.4.1), high CEC values are associated with a higher fraction of clay minerals (e.g. illite and interstratified minerals) in shale derived-soils (Conradie *et al*., 2002). Kaolinite, which is associated with low CEC values (White, 1987), has been found to be predominant in the Western Cape soils (Van Schoor, 2001).

No significant differences were observed in terms of organic carbon (C), total nitrogen (N) and nitrate between shale- and granite-derived soils in all the horizons when all the soils from all the localities were combined (Table 3.3b). The C content in the B horizon for both granite- and shale derived soils was higher than expected for the Western Cape soils but the C: N ratio was within the norm. Comparison of farms showed that, A horizons at S1 and C2 had significantly higher contents of C than those at S2 (Appendix 3C, Table 3.4a). At C2, the shale- contributed more to the total C content than granite-derived soils (Appendix 3C, Table 3.4b). However, according to Stevenson (1986), the C content of soils is normally related to the prevailing climatic conditions during the process of soil formation and not to the parent material. Among all the localities, S1 and C2 have the highest altitudes 400 m and 288 m, respectively. Furthermore, organic-N content for A-horizons at S1 was found significantly higher than that at S2 (Appendix 3C, Table 3.5). This was probably due to mineralisation of organic material proceeding at a slower rate at S1, as a result of cooler conditions (S1 situated at a higher altitude than S2). Furthermore, according to Conradie *et al*. (2002), in cases where the organic matter content is greater than 1%, which was observed at S1, C2 and S1, sufficient N can be supplied by soils to satisfy a demand for grapevines. Nitrate (NO_3-N) was found in very low concentrations when all the soils were combined (Table 3.3b), this was probably due to leaching or low mineralization rates as soil samples were taken during the winter period.

Table 3.3b Effect of granite and shale on the organic matter (C and N) content of some Helderberg soils.

Horizons	A		B1		B2	
Soil property	Granite	Shale	Granite	Shale	Granite	Shale
C (%)	1.77 a	1.85 a	1.32 a	1.29 a	1.03 a	1.02 a
N (%)	0.12 a	0.12 a	0.09 a	0.09 a	0.07 a	0.08a
$N0_3$-N (mg ℓ^{-1})	0.84 a	1.20 a	0.46 a	0.50 a	0.66 a	0.31 a

Values in the same row with different letters indicate differences ($P \leq 0.1$).

Mixture of parent materials as weathering occurred may have masked the effect of geological differences in the soil. Furthermore, these soils underwent various farming practices such as fertilisation, liming and irrigation which may have modified them to a large extent and probably marginalized the effect of geology.

3.4.4 Potassium Quantity/Intensity (Q/I) parameters

Quantity/intensity curves describe the relationship between quantity (Q) and intensity (I) of a nutrient present in the soil. The Q/I relationship for the soils are explained by equations. The equation for the shale-derived soil from C1 was $y = 25.01x - 0.87$, $R^2 = 0.91$ (Appendix 3D, Figure 3.1a), where y = change in K (ΔK), and x is the activity ratio for K (AR^K) and 25.01 is the potential buffering capacity for K (PBC^K). For the granite-derived soil, from C1, the equation y = 41.26x – 3.99, R^2 = 0.95 was obtained (Appendix 3D, Figure 3.1b). The equilibrium activity ratio for K was determined from the Q/I curves when (ΔK) = 0 (the point when no K adsorption or desorption occurred) and represents a measure of the intensity of K in solution (Becket, 1964). Equilibrium activity ratios can be related to the exchangeable K content of the soil (Sumner, 2000). Potential buffering capacity for K for a soil measures the amount of labile K a soil can supply at a given energy level (Saleque *et al*., 2009). Furthermore, the parameter PBC^K is supposedly proportional to the CEC of the soil (Beckett & Nafady, 1967). The Q/I parameters showed no consistent relationship with parent material (Table 3.4). This result is consistent with the finding (Section 3.4.1) that the clay mineral assemblages in the granite- and shale-derived soils were similar. The PBC^K values ranged from 36.9 – 45.4 cmol kg^{-1}. (mol $\ell^{-1})^{1/2}$. The AR^K_e values were low, ranging from 0.03 - 0.09 (mol $\ell^{-1})^{1/2}$. These results suggested that very little K was present on the exchange complex. Very low exchangeable K percentages are associated with an absence of mica (Bühmann, 2004). This supports the finding that the granite- and shale-derived soils contained little or none of this mineral. In other studies, even soils developed from the same parent materials have been found quite different in K dynamics through the application of the Q/I method (Saleque *et al*., 2009).

Table 3.4 Estimated potential buffering capacity of K (PBC^K) and equilibrium potassium activity ratio (AR^K_e) derived from Quantity/Intensity (Q/I) curves for granite- and shale-derived A-horizon soils from Cabernet Sauvignon vineyards (C1 and C2) in Helderberg.

Experimental vineyard	Geology	PBC^K [cmol kg^{-1}. (mol $\ell^{-1})^{1/2}$]	AR^K_e (mol $\ell^{-1})^{1/2}$
C1	Granite	39.0	0.03
C1	Shale	45.4	0.05
C2	Granite	40.2	0.09
C2	Shale	36.9	0.04

PBC^K and AR_e^K, represent potential buffering capacity and equilibrium activity ratio for K, respectively.

In contrast to PBC^K, CEC is a measure of the ability of the exchange complex (organic + inorganic) to exchange cations on a none specific basis (Wooldridge, 1988). Where the shale- and granite-derived soils were combined, there was a negative weak correlation between PBC^K and CEC (Appendix 3D, Figs. 3.2a). Wooldridge (1988), also found low levels of correlation between PBC^k and CEC for limed Western Cape soils and concluded that this was due to the fact that whilst liming induced increases in CEC, the increases in PBC^K induced by liming were disproportionately large. Beckett & Nafady (1968) also observed a poor relationship between CEC and PBC^K for Ca saturated soils. On the other hand, Thompson (1985) found a strong correlation (r = 0.76) between PBC^K and CEC for some Western Cape soils. Relationships between PBC^K and clay content, organic C and the activity ratio, and between AR^K_e and exchangeable K were not significantly (P = 0.05) correlated (not shown). For this population of vineyard soils it was therefore not possible to estimate PBC^K from CEC. The K-supplying of the granite- and shale-derived soils was difficult to evaluate by using the Q/I method probably due to mixing of parent materials that had occurred in the studied A-horizon soils.

3.4.5 Soil water content

Soil water contents were determined for the 2006/2007 and 2007/2008 seasons. Water holding capacity values for all the localities are presented in Table 3.5 and the water contents at field capacity (-10 kPa) and permanent wilting point (-1500 kPa) that these values were calculated from are in Appendix 3E, Table 3.1. Soil water contents decreased towards ripening for both granite- and shale-derived soils.

Soil water content curves for S1 (2006/2007 season) are shown in Figs. 3.4a-c. Similar trends were observed for the soil water content curves determined in the 2007/2008 season (Appendix 3E, Figs. 3.1a-c). Water holding capacity values for both the 300-600 mm and 600-900 mm layers appeared to be higher for shale- than granite-derived soils (Table 3.5). This illustrates that, in general, the shale- supplied more water than the granite-derived soil. Soil water content curves for S2 are shown in Appendix 3E, Figs. 3.2a-b and water holding capacity values for the 600-900 mm layers appeared higher for shale-than granite-derived soils (Table 3.5). Comparisons could not be made in the 0-300 mm and 300-600 mm layers due to difficulty in identifying reliable values for field capacity and permanent wilting point. Soil water content curves for C1 (2006/2007-2007/2008) are shown in Appendix 3E, Figs. 3.3a-f. Water holding capacity values for the 300-600 mm and 600-900 mm layers appeared higher for shale-than granite-derived soils (Table 3.5). Comparisons could not be made in the 0-300 mm layer, also due to difficulty in identifying reliable values for field capacity and permanent wilting point. Soil water content curves for the rain fed site, C2, for the 2006/2007 season are shown in Figs. 3.5a-c and those for the 2007/2008 season are shown in Appendix 3E, Figs. 3.4a-c. Water holding capacity values also appeared higher for shale-than granite-derived soils (Table 3.5).

Table 3.5 Water holding capacities for granite and shale soils from Sauvignon blanc (S1 and S2) and Cabernet Sauvignon (C1 and C2) vineyards in Helderberg.

Experimental vineyard	Geology	Water holding capacity (g $100g^{-1}$)			
		0-300 mm	300-600 mm	600-900 mm	0-900 mm
S1	Granite	11.9	12.2	12.5	36.6
	Shale	11.3	17.9	14.9	44.1
S2	Granite	*	*	6.21	**
	Shale	8.12	12.7	13.1	33.9
C1	Granite	*	10.1	10.5	**
	Shale	12.7	13.1	12.5	38.3
C2	Granite	11.8	13.8	14.8	40.4
	Shale	16.8	17.9	17.3	52.0

* Not available due difficulty in identifying reliable values for field capacity and permanent wilting point.
**Missing values

In general, shale- appeared to have higher water holding capacities than granite-derived soils. With very few exceptions, these results suggested that geological parent material may have a large effect on the hydrological properties of a specific soil, even though soil chemical properties and/or mineralogy may not be affected to the same extent. As shown previously, geology affected the fine and coarse sand distribution pattern, with shale-derived soils having more fine sand than granite-derived soils and the opposite being true in terms of coarse sand, i.e. higher on granite- than shale-derived soils. This puts more emphasis on the soil water regime of a specific soil, rather than on geology *per se,* as recently reviewed by Maltman (2008). Due to differences in sand fractions (fine and coarse) and water contents, grapevines on shale- may be less water stressed than those on granite-derived soils, especially during high temperature periods that usually occur before ripening.

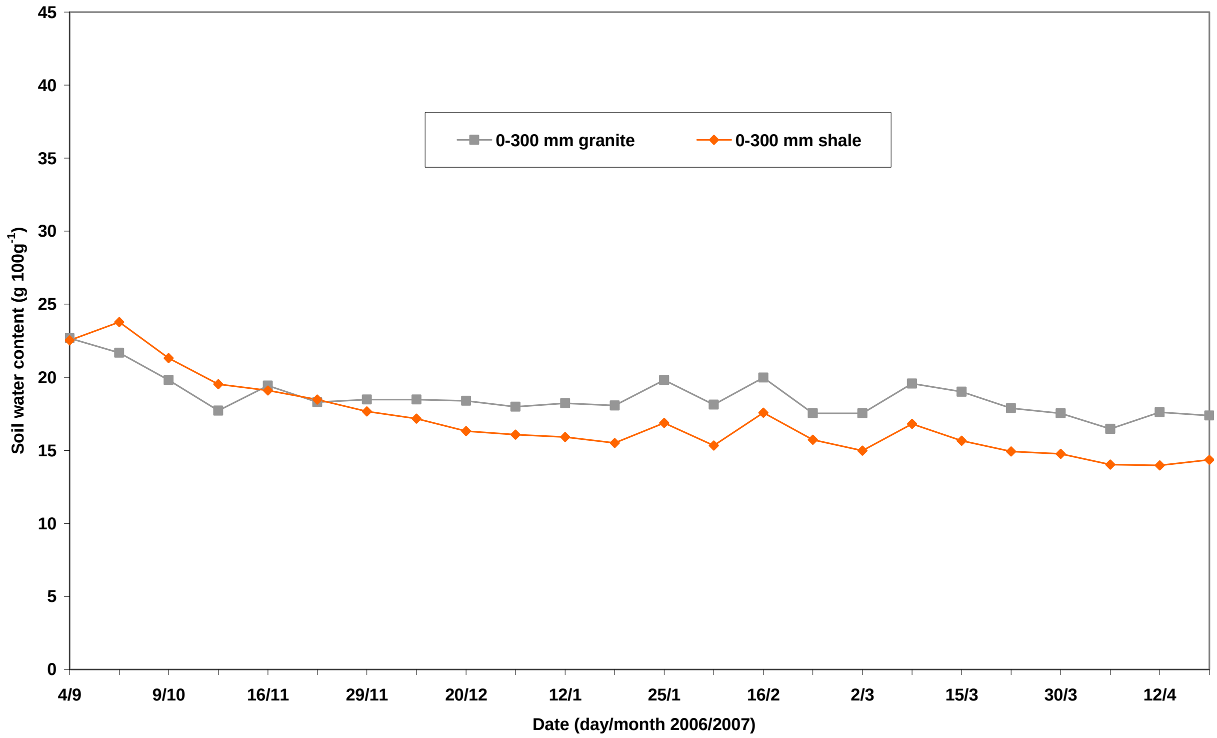

Figure 3.4a Soil water content during the 2006/2007 season for granite- and shale- derived soils (0-300 mm) in a Sauvignon blanc vineyard (S1) in Helderberg.

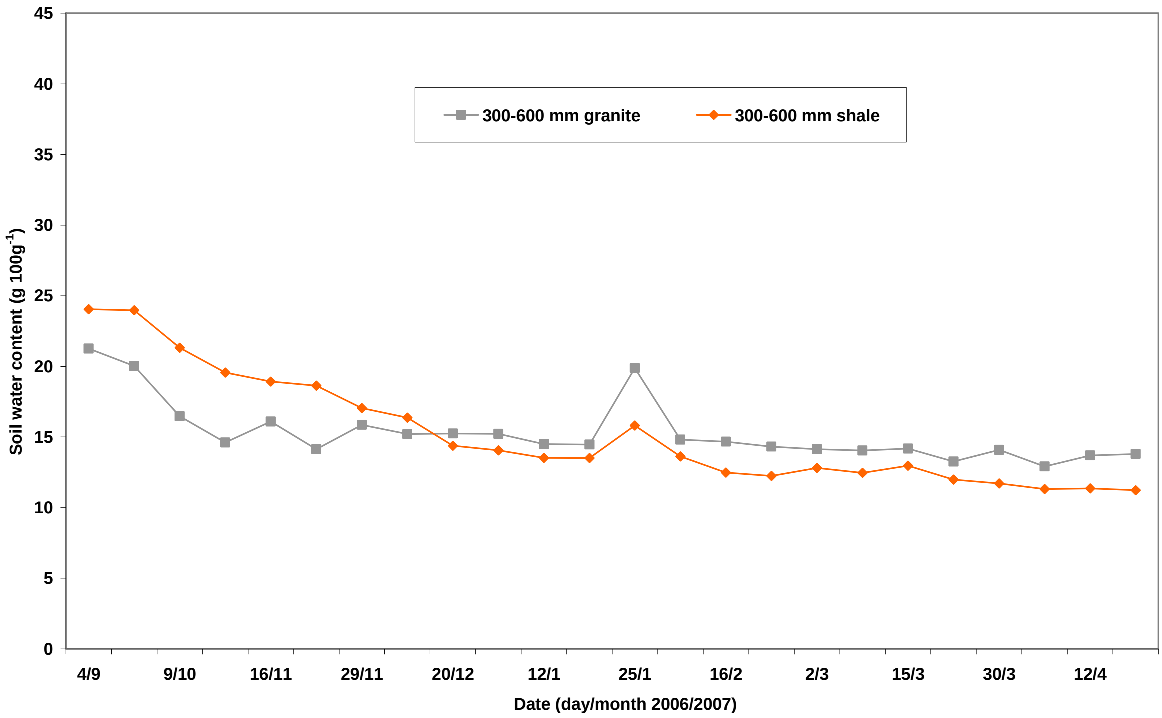

Figure 3.4b Soil water content during the 2006/2007 season for granite- and shale- derived soils (300-600 mm) in a Sauvignon blanc vineyard (S1) in Helderberg.

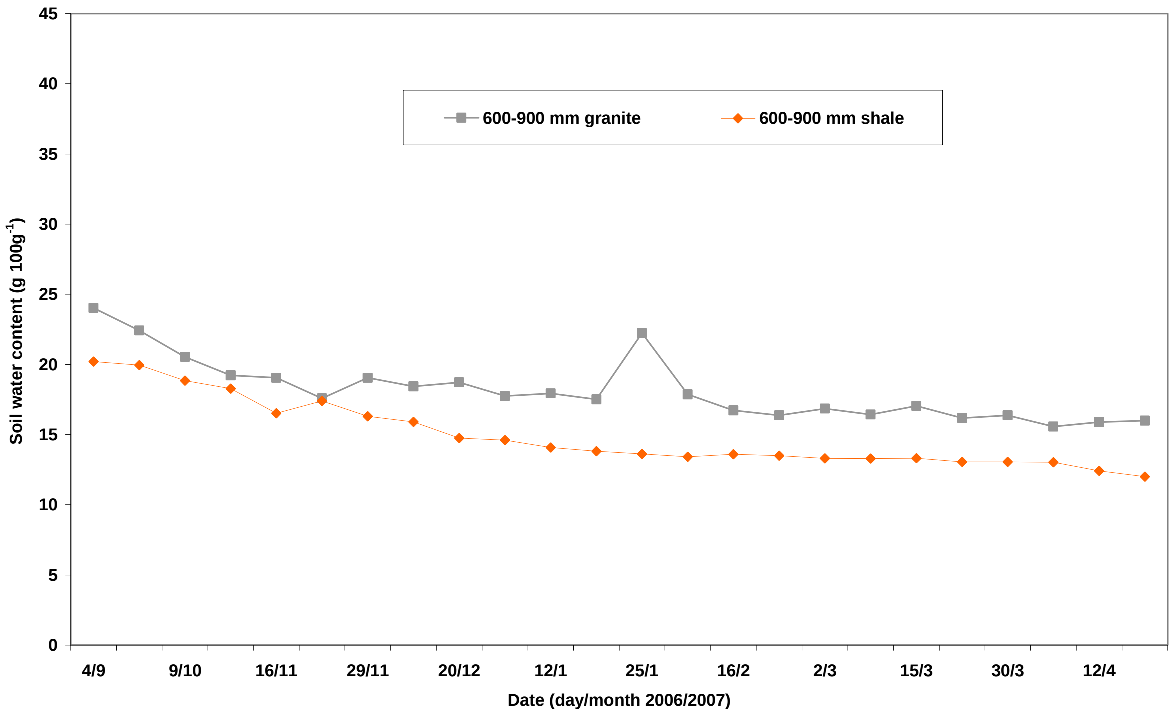

Figure 3.4c Soil water content during the 2006/2007 season for granite- and shale- derived soils (600-900 mm) in a Sauvignon blanc vineyard (S1) in Helderberg.

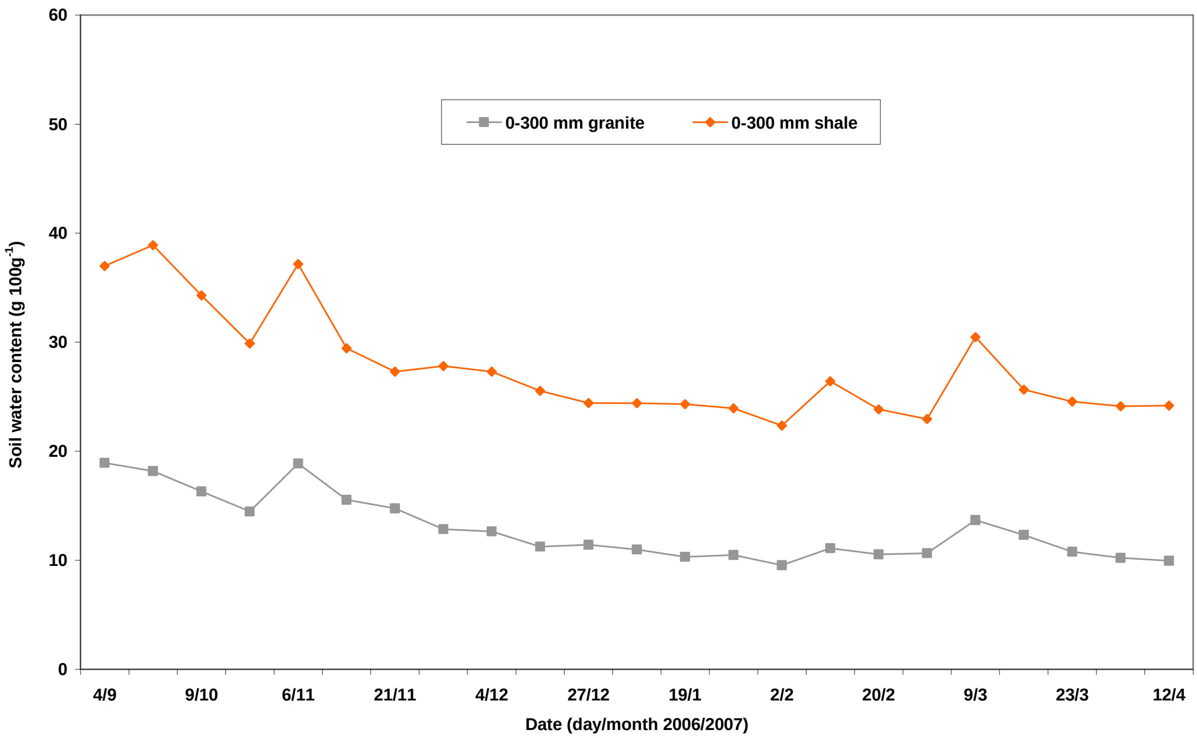

Figure 3.5a Soil water content during the 2006/2007 season for granite- and shale- derived soils (0-300 mm) in a rain fed Cabernet Sauvignon vineyard (C2) in Helderberg.

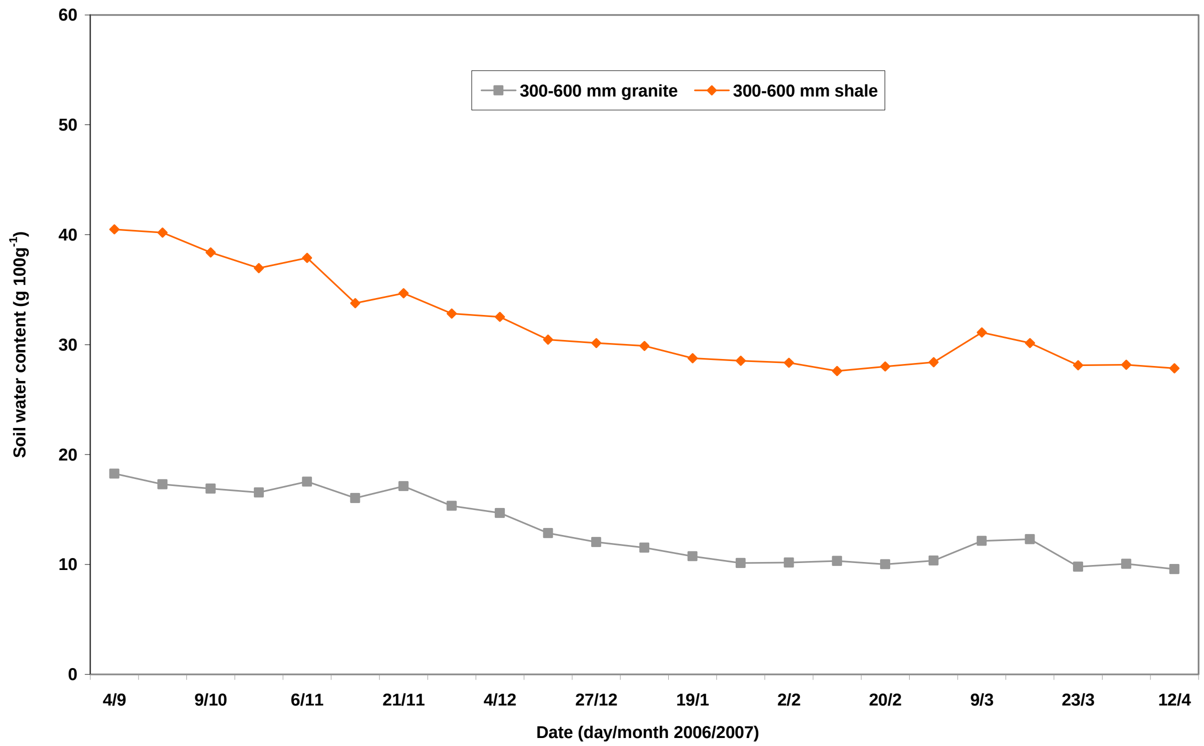

Figure 3.5b Soil water content during the 2006/2007 season for granite- and shale- derived soils (300-600 mm) in a rain fed Cabernet Sauvignon vineyard (C2) in Helderberg.

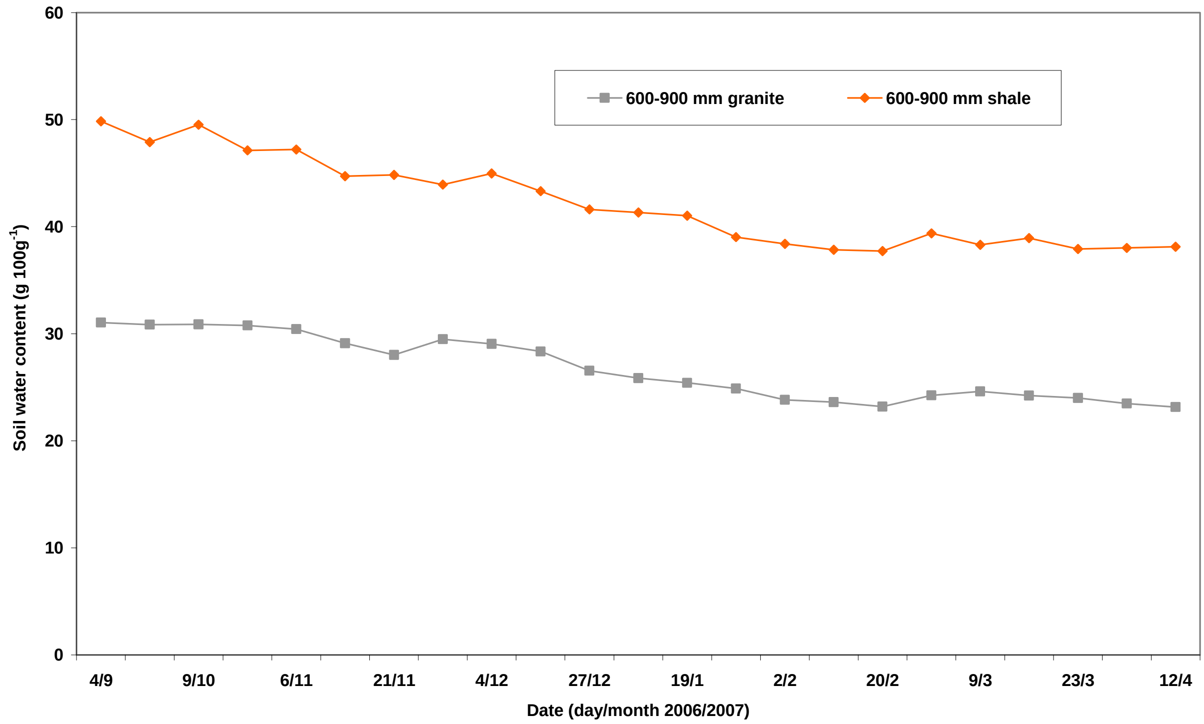

Figure 3.5c Soil water content during the 2006/2007 season for granite- and shale- derived soils (600-900 mm) in a rain fed Cabernet Sauvignon vineyard (C2) in Helderberg.

3.5 CONCLUSIONS

The investigated soils were highly weathered, hence the insignificant effect of geology on clay mineralogy. It appeared that granite-derived soils have a higher ability to release K than shale-derived soils, but K fertilisation may have contributed towards this result. Total K being higher in shale- than granite-derived soils pointed to shale derived-soils as having a higher capacity to fix added K. The differences in particle size distribution indicated an effect of geology, especially in the B horizons, whilst mixing of parent materials apparently occurred in the A horizons. Differences in soil water content indicated that parent material may have an indirect effect on the hydrological properties of a specific soil. Shale- appeared to have a higher water holding capacity than the granite-derived soils. Soil preparation practices and fertilisation can play a huge role in altering soil composition, thus diminishing geological effects on the nutritional status of the soil.

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Chapter 4

Research results

Grapevine nutritional status of geologically different sites

CHAPTER 4: RESEARCH RESULTS

4.1 ABSTRACT

The occurrence of different geological parent materials which may change from granite to shale over a short distance within the same vineyard block is of special significance in the Helderberg area. Currently there is little scientific information regarding the effect of different geological parent materials on grapevine performance in South Africa. The objectives of this study were to investigate (i) the impact of geological differences in the soil on the vine nutritional status (ii) the impact of geological differences in the soil on certain vine parameters that were related to nutrient uptake and distribution in the vines. In this study that was done over two seasons (2006/2007 and 2007/2008), Sauvignon blanc and Cabernet Sauvignon experimental plots were established on four commercial farms in the Helderberg area (near Somerset West, South Africa) within the same vineyard block.

Leaf blades, petioles and berry juice were analyzed chemically. Vine parameters that could affect nutrient uptake as well as water and mineral absorption were investigated. The ability of the root system to function efficiently was found more dependent on soil preparation before planting than on geology. Potassium concentrations were higher in the leaf blades (obtained before harvest in 2007) for Sauvignon blanc grapevines from granite- than from shale-derived soils. Potassium concentrations in the Cabernet Sauvignon juice (obtained in 2007) tended higher for juice on granite- than shale-derived soils. In contrast, in 2008, for both cultivars, K concentrations tended higher for juice from shale- than from granite-derived soils. The pH of the Sauvignon blanc juice (obtained in 2008) tended higher for juice from shale-than from granite-derived soils, thus corresponding with the K concentrations of the juice in this season. Nitrogen concentrations in the leaf blades (obtained after flowering in 2006 and before harvest in 2007) were higher for Sauvignon blanc grapevines on shale- than on granite-derived soils. Concentrations of soluble K and N in the soils corresponded with concentrations of K and N in the leaf blades. Nitrogen concentrations were higher for Cabernet Sauvignon juice (obtained in 2007) and Sauvignon blanc juice (obtained in 2008) on shale- than on granite-derived soils. In terms of vine water status, vines on granite-derived soils at one of the vineyards appeared more stressed than those on shale-derived soils in both seasons.

In these vineyards, the K nutritional status of the Sauvignon blanc and Cabernet Sauvignon vines was not affected by geology in a consistent manner, although there were some noticeable responses for some cultivars in certain seasons. The vines in each experimental vineyard block underwent similar soil preparation practices, similar fertilisation programmes, were exposed to a similar irrigation schedule, similar canopy management strategies and grew under similar climatic conditions. All these practices may have marginalized the effect of geology on the K status of the vines. However, it was clear that the seasonal differences and fertilisation affected the nutritional status of the vines more than geology.

Keywords: Geology, granite, shale, grapevine, potassium

4.2 INTRODUCTION

Geology (parent material) and soil forming processes lead to the formation of soils with specific, definable characteristics. The nutrient status of the soil is widely accepted to be related to the parent material (its mineralogical composition) that soil has been derived from (McBride, 1994). In South Africa, a large percentage of vineyard soils in the Western Cape is derived from the parent materials, granite, shale and sandstone (Van Schoor, 2001; Bargmann, 2005). Wooldridge (1988) observed that, granite soils of the Western Cape area are relatively rich in potassium (K). Soils originating from phyllitic shales were found with the lowest K levels in comparison to granite and sandstone originating soils (Conradie *et al*., 2002). Granite-derived soils were found with a low buffering capacity for K (Wooldridge, 1988). Italian rye grasses grown in these granitic soils showed a luxurious consumption of K in comparison to those that were grown in shale originating soils. Luxurious consumption of K may occur in vineyards planted on granite rich soils as well (Wooldridge, 2005). Potassium and nitrogen (N) are the two elements that may have a significant effect on wine quality especially if no serious deficiencies of other essential elements exist (Saayman, 1992; Conradie, 1994). Excessive K in soils may affect red wine quality by increasing the pH (Somers, 1975, Conradie, 1994), which is undesirable for wine production purposes. In addition, Mg deficiencies could also be induced by excessive concentrations of K in the soil (Conradie, 1981). Soil K levels, may also have a substantial effect on the acid balance of the grape juice and wine pH (Conradie & Saayman, 1989). In addition, other factors which are associated with the vine may also affect the uptake and distribution of K in the grapevines (Mpelasoka *et al*., 2003), for example root system efficiency, vine water status, canopy density and the vine nutrient status. These factors need to be investigated together with the soil K status when evaluating the K nutrient status in the vineyards. In the Western Cape region, especially the Helderberg area, parent material may change from granite to shale over a short distance, thus resulting in shale- as well as granite-derived soils often occurring within the same vineyard. The impact of parent materials (granite and shale) on the soil K status has been studied in citrus soils (Wooldridge, 1988) and vineyard soils of the Western Cape (Van Schoor, 2001; Engelbrecht & Saayman, 2005; Agenbach, 2006). The purpose of this study was to investigate the vine K status in vines on geologically different soils (granite- and shale-derived soils) in the Helderberg area, through quantifying differences between these parent materials in terms of K supply and the impact thereof on the leaf blade and berry K status, while also taking into consideration other factors (soil and vine related) that may affect K uptake and distribution in the grapevines.

4.3 MATERIALS AND METHODS

4.3.1 Vineyards

The field investigation was planned as described in Chapter 3, section 3.3.1. Planting material may have been obtained from different commercial nurseries as these were different farms. Canopy management and irrigation scheduling also differed from one farm to another. Planting widths were 2.75 x 1.0 m at S1, 2.70 x 1.20 m at S2 and 2.50 x 1.25 m at C1 and C2. Vines were trained on vertical trellis systems (one wire for the cordon arms and two to four wires for the foliage). Spur pruning was done annually, while suckering was done before flowering. All vineyards were drip irrigated, except C2, which was non-irrigated (rain-fed). Rootstocks that were used are presented in section 4.4.1, Table 4.1.

4.3.2 Experiment layout

Within each vineyard, experimental plots on shale- and granite- derived soils were selected. Three experimental vines were selected from two adjacent rows, resulting in six opposing vines per plot. To measure the impact of seasonal changes, weather stations were erected on each farm, except for S2. On account of S2 being close (≈200 m) to C1, data from the latter was also used for S2.

4.3.3 Data collection and analyses

4.3.3.1 Root distribution

Root distribution was determined by the use of a grid method on each of the root systems of the 48 vines. A 1 m^2 (1 m deep and 1 m wide) frame with a 25 cm x 25 cm inner string grid was placed on a surface of an exposed root system with the vine centrally positioned and the total number of thin (diameter ≤ 2 mm) and thick (diameter >2 mm) roots per grid were recorded.

4.3.3.2 Leaf and petiole analyses

For the six experimental vines, leaf blades were sampled a week after flowering in 2006 and a week before harvest in 2007. In 2008, for comparison purposes, leaf blades and petioles were sampled from only Cabernet Sauvignon vineyards a week before harvest. Four leaf blades opposite flowers and bunches were selected from each vine. Leaf blades and petioles were immediately separated at sampling and dried at 50 ^{0}C for 12 hours and further prepared and analyzed according to the standard methods of BemLab (Campbell & Plank, 1998; Miller, 1998) for N, P K, Ca Mg and Na.

4.3.3.3 Juice analyses

From each vine about 100 berries (top, middle and bottom berries per bunch) were representatively sampled during the harvesting period, thereafter crushed (by hand in a clean plastic bag) to obtain juice, which was analyzed for pH, sugar content and titratable acidity by the Infruitec-Nietvoorbij cellar. Concentrations of N, P, K, Ca, Mg and Na in juice were determined according to the standard methods of BemLab.

4.3.3.4 Vine parameters

Trunk circumference was measured in winter with a measuring tape at 1 cm above the graft union from each experimental vine. Canopy density measurements were performed by using the point quadrat method (Smart & Robinson, 1991). After véraison (2007 and 2008), a thin metal rod was inserted perpendicularly into the canopy (fruit zone) of each vine. Ten insertions were made in each vine and contact with leaves and clusters were noted. During winter (July 2007), grapevines were hand pruned to two spurs and cane masses were determined, except at S1 and S2, where pruning had accidentally already been done by the producer. In 2008, the number of bunches per vine were recorded and yield per vine was determined. The yield and the number of bunches per vine, were not determined in 2007 and cane mass and trunk circumference were not determined in 2008.

4.3.3.5 Leaf water potential

Midday leaf water potentials (LWP) were measured between 12h00 and 14h00 with the aid of a pressure chamber. The readings were taken weekly from after flowering until post harvest. Four uncovered, mature leaves that were fully exposed to sunlight, were used.

4.3.3.6 Statistical analyses

Analysis of variance was performed on all variables using the general linear models (GLM) procedure of SAS statistical software version 9.1 (SAS, 2000). The Shapiro-Wilk test was performed to test for normality (Shapiro & Wilk, 1965). Student's t-least significant difference was calculated at the 10 % levels to compare treatment means (Snedecor & Cochran, 1980). Where data could not be analyzed statistically due to a smaller sample number per plot, means were used to compare between treatments. Since there were no significant differences in terms of important nutrients in the soil between treatments (refer to Chapter 3), no correlation studies were done between nutrients of plant material and soil.

4.4 RESULTS AND DISCUSSION

4.4.1 Root distribution

The rootstock types and results of root studies are shown in Table 4.1. Although these were different farms, for Cabernet Sauvignon, similar rootstocks were used but for Sauvignon blanc, rootstock types varied with farms. For this study, more emphasis was put on the physical distribution of the roots than on the rootstock types as rootstocks were similar for vines that were both on granite- and on shale-derived soils within a vineyard block. There were more fine roots than thick roots in both granite- and shale-derived soils. Fine roots are considered more important than thick roots as they play a decisive role in the qualitative performance of vines during warm dry summers (Archer & Hunter, 2005). At S1, fine and thick roots were evenly distributed for both granite- and shale-derived soils in all horizons (Table 4.1). Density of fine roots in granite-derived soil appeared to be higher than that in shale-derived soil, but that of thick roots appeared to be higher in shale- than in granite-derived soil. At S2, the fine root density appeared to be higher in granite-derived soil, whilst the fraction of fine roots in the 600-900 mm horizon was 10 % higher in shale- than in granite-derived horizon. At C1, the fine root density in shale- appeared to be higher than that in granite-derived soil. Moreover, a fraction of fine roots in the 300-600 mm and 600-900 mm horizons appeared to be higher in shale- than in granite-derived soil. In contrast to C1, at C2, density of fine roots and a fraction of fine roots in the 600-900 mm horizon appeared to be higher in granite- than in shale-derived soils.

According to Archer & Schloms (2001), the fine root density indicates the quality of the root system. Consequently, the quality of the root system in granite-derived soil at S1, S2 and C2 sites may be considered better than that of the root system in the shale-derived soil. However, towards véraison the fine roots in deep horizons are more important than those in the upper horizons, thus implying that a slightly higher fraction of fine roots in the deeper layers of the shale- than granite-derived soils at S1, S2 and C1 may play a very critical role in improving root system efficiency. The quality of a root system is highly affected by the method and efficiency of chemical and physical soil preparation (Archer & Hunter, 2005). Furthermore, root distribution within a specific parent material was found to be affected to a larger extent by factors such soil moisture, compacted soil layer and percentage stone than geological differences in certain Western Cape soils (Conradie *et al*., 2002). Root distribution was expected to may have been affected by the differences in fine and coarse sand contents due to geological differences (refer to Chapter 3, section 3.4.1). However, on account of the absence of a consistent pattern in root distribution in these geologically different soils, soil preparation before planting may have affected root distribution and the quality of the root systems more than the geological differences.

Table 4.1 Root distribution in geologically (granite and shale) different soils in the Helderberg area.

Vineyard/ rootstock	Geology	Root distribution (%)						Root density per m^2 profile	
		Fine roots (≤2.0 mm diameter)			Thick roots (>2.0 mm diameter)			Fine roots	Thick roots
		0-300 mm	300-600 mm	600-900 mm	0-300 mm	300-600 mm	600-900 mm	(≤ 2.0 mm diameter)	(> 2.0 mm diameter)
S1/ 110 Richter	granite	57.1	29.3	13.7	41.9	35.6	22.6	264	56
	shale	51.6	30.5	17.9	45.2	33.1	21.7	191	88
S2/ Richter 99	granite	27.8	40.8	31.4	28.9	44.0	27.1	142	60
	shale	22.2	35.1	42.6	22.9	45.1	32.0	89.0	42
C1/ 110 Richter	granite	64.2	21.9	14.0	64.4	26.9	8.70	111	33
	shale	46.4	32.4	21.2	39.8	44.2	15.9	207	52
C2/ 110 Richter	granite	46.2	35.1	18.7	29.8	46.4	23.8	277	34
	shale	45.1	43.9	11.0	27.9	53.1	19.0	195	22

4.4.2 Leaf nutrient status

Concentrations of macronutrients in the leaf blades of Sauvignon blanc and Cabernet Sauvignon sampled at different periods are shown in Table 4.2a - Table 4.2b. Macro element concentrations of leaf blades, together with that of petioles for Cabernet Sauvignon, are shown in Table 4.2c. For Sauvignon blanc, N concentrations were higher in leaf blades from shale- than from granite-derived soils (Table 4.2a - Table 4.2b). Higher concentrations of soluble K may have suppressed N uptake in the granite-derived soils, as a result of a K/N antagonistic relationship (Conradie, 1994; White, 2003). For Cabernet Sauvignon, although a similar pattern to that of Sauvignon blanc was observed, differences in terms of N concentrations in the leaf blades were not statistically different (Table 4.2a - 4.2c). The Cabernet Sauvignon vineyard soils showed that $N0_3$-N concentrations appeared higher in shale- (A and B1-horizons) than granite-derived soils (Appendix 4A, Table 4.1).

For Sauvignon blanc, P concentrations tended higher in leaf blades from shale- than from granite-derived soils (Table 4.2a - Table 4.2b), thus correlating with levels of P found in the A-horizon soils (Appendix 4A, Table 4.1) at S1 and S2. In contrast, for Cabernet Sauvignon, P concentrations of leaf blades (Table 4.2a - Table 4.2c) and petioles (Table 4.2c) on granite-derived soils tended higher than those of leaf blades on shale-derived soils (Table 4.2a - Table 4.2b). However, this trend was not observed in the A-horizons of the Cabernet Sauvignon vineyards, where the opposite was found (Appendix 4A, Table 4.1). Leaf blades of Sauvignon blanc reflected the concentrations of P in the soil better than those of Cabernet Sauvignon.

Table 4.2a Macro element concentrations in leaf blades (obtained one week after flowering in 2006) from vines on geologically (granite and shale) different soils in Helderberg.

Element (%)	Sauvignon blanc		Cabernet Sauvignon	
	Granite	Shale	Granite	Shale
N	1.65 a	1.97 b	1.50 A	1.74 A
P	0.17 a	0.22 a	0.44 A	0.25 A
K	0.93 a	0.90 a	1.04 A	0.88 A
Ca	2.11 a	2.77 a	2.38 A	2.62 B
Mg	0.39 a	0.51 b	0.52 A	0.56 A

Values in the same row with different letters indicate differences (P ≤ 0.1).

Table 4.2b Macro element concentrations in leaf blades (obtained one week before harvest in 2007) from vines on geologically (granite and shale) different soils in Helderberg.

Element (%)	Sauvignon blanc		Cabernet Sauvignon	
	Granite	Shale	Granite	Shale
N	2.46 a	2.62 b	2.30 A	2.46 A
P	0.32 a	0.43 a	0.76 A	0.45 A
K	0.90 a	0.79 b	1.01 A	0.92 A
Ca	2.16 a	2.80 a	2.63 A	2.50 A
Mg	0.38 a	0.45 a	0.50 A	0.50 A

Values in the same row with different letters indicate differences (P ≤ 0.1).

Table 4.2c Macro element concentrations in Cabernet Sauvignon leaf blades and petioles (obtained at harvest in 2008) from vines on geologically (granite and shale) different soils in Helderberg.

Element (%)	Leaf blades		Petioles	
	Granite	Shale	Granite	Shale
N	1.57 a	1.84 a	0.45 A	0.48 A
P	0.22 a	0.16 a	0.56 A	0.23 A
K	0.94 a	0.93 a	2.68 A	2.22 A
Ca	2.20 a	2.46 a	1.71 A	1.83 A
Mg	0.54 a	0.54 a	1.92 A	2.15 A

Values in the same row with different letters indicate differences (P ≤ 0.1).

For Sauvignon blanc leaf blades (obtained in 2006 after flowering), insignificant differences were obtained in terms of K levels between granite- and shale-derived soils (Table 4.2a), but before harvest samples showed that K concentrations of leaf blades from granite-derived soils were higher than those from shale-derived soils (Table 4.2b). In the Sauvignon blanc vineyard (S1 and S2) soils, soluble K was higher in granite-derived (both B-horizons) than in shale-derived soils (Appendix 4A, Table 4.1). Furthermore, although not observed in the mineralogical results for these soils (Wooldridge, 1988) found that granite is relatively rich in K containing minerals. Moreover, such kaolinitic granite-derived soils were found to have a low buffering capacity for K and promoted luxurious consumption of K in grasses. For Cabernet Sauvignon, K concentration tendencies similar to those in the leaf blades of Sauvignon blanc were observed in some leaf blades (Table 4.2a) and petioles (Table 4.2c). For Cabernet Sauvignon vineyard (C1 and C2) soils, soluble K concentrations were similar in both soil types (A and B1 horizons) and only tended higher in the B2-horizons of shale- than of granite-derived soils (Appendix 4A, Table 4.1), implying that K concentration in the soil is not the only factor that determine concentrations of K in the plant material.

For Sauvignon blanc, Ca concentrations of leaf blades on shale-derived soils tended higher than those on granite-derived soils (Table 4.2a and Table 4.2b). For Cabernet Sauvignon, similar but stronger tendencies were observed in 2006 (Table 4.2a). Calcium supply to the above ground organs mainly depend on transpiration intensity (Mengel & Kirby, 1987). Furthermore, soluble Ca concentrations, especially in the B-horizons, appear to be higher for shale- than granite-derived soils for both cultivars (Appendix 4A, Table 4.1). For Sauvignon blanc, Mg concentrations were higher in leaf blades (obtained after flowering) from shale- than those from granite-derived soils (Table 4.2a). Similar tendencies were observed for Sauvignon blanc leaf blades obtained before harvest (Table 4.2b). Here, soluble and exchangeable Mg concentrations appear to be higher in both B-horizons of shale- than of granite-derived soils (Appendix 4A, Table 4.1). For Cabernet Sauvignon, although soluble Mg concentrations in the soil tended to be higher for shale- (A and B2 horizons) than granite-derived soils, Mg concentrations in the leaf blades (Table 4.2a - Table 4.2c) and petioles (Table 4.2c) on both soil types were similar.

The effect of the differences in the soil on the nutrient content (especially K and N) in the leaf blades appeared more prominent in Sauvignon blanc than Cabernet Sauvignon vines. Concentrations of certain elements (soluble K and NO_3-N) in the soil seemed to relate with those in the leaf blades to a certain extent, especially in the case of Sauvignon blanc. However, these results indicated that concentrations of nutrients in the soil are not the only ones that determine levels of nutrients found in the plant material, thus further making it more complicated to quantify the effects of geology on plant material. Overall, seasonal effects and fertilisation seemed to play a bigger role in affecting the nutritional status of grapevines than geology.

4.4.3 Juice nutrient status

Concentrations of macronutrients in the juice of Sauvignon blanc and Cabernet Sauvignon obtained in 2007 and 2008 are shown in Table 4.3a and Table 4.3b, respectively. Nitrogen concentrations were higher in Cabernet Sauvignon (Table 4.3a) and Sauvignon blanc (Table 4.3b) juice from shale- than from granite-derived soils, thus corresponding with N concentrations in the leaf blades. For the rest of the results, a similar pattern was observed, even though the differences were not significant. In the case of Sauvignon blanc juice obtained in 2008, K concentrations in juice of vines on shale-derived soils did not seem to have largely affected the N concentrations in the juice of these vines, as they still remained higher in juice from shale- than from granite-derived soils. According to Myburgh (2006), high levels of water depletion can cause high levels of juice N content for Sauvignon blanc. According to Williams & Matthews (1990), water deficits during ripening may cause amino acid accumulation in the juice of water stressed grapevines. Furthermore, a significant increase of proline in juice of grapevines by water stress was observed by Matthews & Anderson (1988). Proline is one of the predominating amino acids in Sauvignon blanc grapes (Kliewer, 1970). In this study, shale- which supplied more water than the granite-derived soil (refer to chapter 3, section 3.4.5), also obtained higher juice N concentrations.

Phosphorus concentrations were similar for Sauvignon blanc juice obtained in 2007 from both granite- and shale derived soils (Table 4.3a). However, for the juice obtained in 2008, P concentrations tended higher for juice from granite- than from shale-derived soils (Table 4.3b), which did not correspond with the P concentrations in the soil and in leaf blades. For Cabernet Sauvignon, larger apparent differences were observed as P concentrations were higher for juice on granite- than shale-derived soils (Table 4.3b), which corresponded with P concentrations in the leaf blades and petioles (refer to section 4.4.2). This suggested that P uptake and/or subsequent translocation to the Cabernet Sauvignon berries might have been limited on shale-derived soils.

In terms of K, insignificant differences between granite- and shale-derived soils were found for both cultivars for the 2007 harvest, but some tendencies were observed in certain cases. Potassium concentrations in Cabernet Sauvignon juice from granite-derived soils tended higher than that in juice from shale-derived soils (Table 4.3a), which is an expected tendency. These results corresponded with the K concentrations in the leaf blades (sampled in 2006) but not with K concentrations in the soils (Appendix 4A, Table 4.1). In the case of K concentration in the juice at harvest, the soil K content has been indicated to be the least important factor compared to water stress after véraison, shoot growth at véraison and within canopy shade in certain Western Cape vineyards (Agenbach, 2006). Moreover, with the granite derived-soils generally having a lower water holding capacity than shale-derived soils (refer to Chapter 3), water stress may have contributed to higher juice K in granite- than shale-derived soils. Water stress may reduce photosynthetic activity of leaves, resulting in an increased accumulation of K in berries (Freeman *et al*., 1982; Iland, 1988). In contrast to what was observed in the 2007 harvest, in 2008, K concentrations in juice from shale-derived soils tended to be higher than that in juice from granite-derived soils (Table 4.3a and Table 4.3b). This may have been on account of climatic differences (data not shown), which have been found to have a considerable effect on concentrations of grape juice K obtained at harvest (Conradie *et al*., 2002; Agenbach, 2006).

Table 4.3a Concentrations of macro elements in Sauvignon blanc and Cabernet Sauvignon juice samples obtained at harvest in 2007 from vines on geologically (granite and shale) different soils in Helderberg.

Element (mg ℓ^{-1})	Sauvignon blanc		Cabernet Sauvignon	
	Granite	Shale	Granite	Shale
N	283 a	350 a	259 B	282 A
P	94.7 a	98.9 a	213 A	142 A
K	1075 a	1084 a	2053 A	1544 A
Ca	48.3 a	53.6 a	49.2 A	45.3 A
Mg	86.1 a	83.7 a	122 A	108 A

Values in the same row with different letters indicate differences ($P \leq 0.1$).

Calcium concentrations in juice of for both cultivars were similar for both granite- and shale-derived soils in both seasons (Table 4.3a and Table 4.3b). In terms of Mg concentrations, for the juice obtained in 2007, for both cultivars, insignificant differences between soils were observed (Table 4.3a). For the 2008 harvest, Mg concentrations were significantly higher for Sauvignon blanc juice from granite- than from shale-derived soils and a similar pattern but insignificant differences between soils were observed for Cabernet Sauvignon juice (Table 4.3b).

Table 4.3b Concentrations of macro elements in Sauvignon blanc and Cabernet Sauvignon juice samples obtained at harvest in 2008 from geologically (granite and shale) different soils in Helderberg.

Element (mg ℓ^{-1})	Sauvignon blanc		Cabernet Sauvignon	
	Granite	Shale	Granite	Shale
N	174 b	247 a	218 A	265 A
P	53.1 a	49.2 a	146 A	119 B
K	934.3 a	1012 a	1267 A	1381 A
Ca	46.3 a	51.5 a	32.2 A	29.9 A
Mg	87.0 a	78.0 b	129 A	109 A

Values in the same row with different letters indicate differences ($P \leq 0.1$).

In general, in some cases concentrations of nutrients in the juice seem to relate with those in the leaf blades. Therefore, translocation of nutrients from the leaf blades to the berries seems to have occurred in certain cases. Similarly to the observations made in the leaf blades, seasonal effects seem to have contributed more to the nutrient status in the juice than geology.

4.4.4 Must composition

For both seasons and cultivars, the time of harvest was not affected by geological differences i.e. grapes on both granite and shale-derived soils (within each experimental vineyard) were harvested on the same day (dates not shown). In general, both cultivars were harvested fairly, close to the ideal sugar contents i.e. 22.5 ^{0}B and 24.0 ^{0}B for Sauvignon blanc and Cabernet Sauvignon, respectively (Table 4.4a and Table 4.4b). However, for Sauvignon blanc, the sugar content for the juice obtained in 2008, tended higher for juice on granite- than shale-derived soils. A higher water holding capacity on shale- than granite-derived soils may have caused slower ripening for vines on shale-derived soils during the 2007/2008 season as there was also more rain in this season than in the 2006/2007 season (data not shown).

Table 4.4a Juice parameters of Sauvignon blanc and Cabernet Sauvignon obtained at harvest in 2007 for geologically (granite and shale) different soils in Helderberg.

Parameter	Sauvignon blanc		Cabernet Sauvignon	
	Granite	Shale	Granite	Shale
Balling (^{0}B)	22.1 a	21.8 a	23.8 A	23.5 A
Titratable acidity (g ℓ^{-1})	7.63 a	7.75 a	6.94 A	6.43 B
pH	3.28 a	3.26 a	3.51 A	3.49 A

Values in the same row with different letters indicate differences ($P \leq 0.1$).

Titratable acidity was similar for Sauvignon blanc juice obtained in 2007 from both soil types (Table 4.4a). However, in 2008, titratable acidity tended higher in juice from granite- than from shale-derived soils (Table 4.4b) and this result was also reflected by apparently slightly lower pH values for juice from granite-derived soils. Titratable acidity in Cabernet Sauvignon juice (obtained in 2007), was higher in juice from granite- than from shale-derived soils (Table 4.4a). For the 2008 harvest, a similar pattern to that observed in the previous season occurred in terms of titratable acidity but the differences between the two soils were insignificant (Table 4.4b).

Table 4.4b Juice parameters of Sauvignon blanc and Cabernet Sauvignon obtained at harvest in 2008 for geologically (granite and shale) different soils in Helderberg.

Parameter	Sauvignon blanc		Cabernet Sauvignon	
	Granite	Shale	Granite	Shale
Balling (^{0}B)	22.2 a	21.1 a	23.2 A	23.4 A
Titratable acidity (g ℓ^{-1})	9.77 a	9.31 a	7.15 A	6.73 A
pH	3.24 a	3.29 a	3.43 A	3.46 A

Values in the same row with different letters indicate differences ($P \leq 0.1$).

The ideal pH values of juice at harvest are between 3.0 to 3.3 for both cultivars, but only Sauvignon blanc conformed to these values in both seasons (Table 4.4a and Table 4.4b). For Sauvignon blanc harvested in 2008, the pH tended to be higher in juice from shale- than from granite-derived soils, thus corresponding with the K concentrations of the juice in this season (see section 4.4.3). However, this trend was not observed in Cabernet Sauvignon juice, thus supporting the view that juice K concentrations do not always relate directly to juice pH (Boulton, 1980). The possible use of different clones (as these were vineyards from different farms) may have had an effect on sugar/ acid/ pH balances, as also indicated by Conradie *et al*. (2002). The 2007 results reflected the possible effects of soil type on must composition more than the 2008 results. Therefore, seasonal effects appear to have played a bigger role in affecting must composition than geology *per se*.

4.4.5 Vine parameters

Canopy density as reflected by leaf layer numbers, did not differ between granite- and shale-derived soils in both seasons for both cultivars (Table 4.5a and Table 4.5b). Trunk circumference was higher for Cabernet Sauvignon vines on granite- than those on shale-derived soils (Table 4.5a). Poor growth conditions caused by lack of soil water have been related to smaller trunk circumferences (Holzapfel *et al*., 2006). Therefore, despite the lower water holding capacity in granite- than shale-derived soils, Cabernet Sauvignon vines on granite-derived soils may have had better growing conditions (related to soil moisture surrounding the root zone) than shale-derived soils in the 2006/2007 season. The cane mass was also found higher for Cabernet Sauvignon vines on granite- than shale-derived soils (Table 4.5a). Differences in pruning mass have been found to be primarily due to cane size (diameter and length) rather than to cane number (Holzapfel *et al*., 2006), consequently, a larger cane size for vines on granite- than on shale-derived soils can be assumed. Furthermore, for both cultivars, the number of bunches on granite-derived soils tended higher than those on shale-derived soils (Table 4.5b) but this was not reflected by the yield, probably on account of smaller berries. The size of berries is associated with water stress levels in the vine (Shellie, 2006), which is in agreement with the soil water status for these vineyards (refer to chapter 3), i.e. granite-derived soils have a lower water holding capacity than the shale-derived soils. Cabernet Sauvignon seems to have reflected differences in vine parameters, as a possible response to geological differences in the soils, better than Sauvignon blanc during 2007.

Table 4.5a Some parameters of vines (measured in 2007) on geologically (granite and shale) different soils in Helderberg.

Parameter	Sauvignon blanc		Cabernet Sauvignon	
	Granite	Shale	Granite	Shale
Cane mass per vine (kg)	*	*	2.07 A	1.59 B
Leaf layer number	3.32 a	3.35 a	2.62 A	2.67 A
Trunk circumference	16.9 a	16.8 a	17.9 A	14.8 B

* Not measured as vines were pruned by the producer.

Values in the same row with different letters indicate differences (P ≤ 0.1).

Table 4.5b Some parameters of vines (measured in 2008) on geologically (granite and shale) different soils in Helderberg.

Parameter	Sauvignon blanc		Cabernet Sauvignon	
	Granite	Shale	Granite	Shale
Yield per vine (kg)	0.98 a	0.99 a	2.27 A	2.38 A
Number of bunches per vine	10.8 a	8.00 a	14.6 A	13.1 A
Leaf layer number	3.66 a	4.01 a	3.09 A	2.88 A

Values in the same row with different letters indicate differences (P ≤ 0.1).

4.4.6 Leaf water potential

For both Sauvignon blanc and Cabernet Sauvignon, leaf water potential (LWP) readings were between -1200 kPa and -1600 kPa for most of the 2006/2007 season, thus indicating that vine water stress ranged from light to high according to Bogart (2000). During the 2007/2008 season, readings of less than -1400 kPa were rarely encountered, thereby suggesting that water stress remained within the light to medium range (-1200 kPa to -1400kPa) during most part of this of season. In this season, readings were obviously affected by irrigation and/or rainfall, with water stress decreasing during February 2008. In terms of rainfall, on average a total of 43 mm of rain was recorded during February 2008 (data not shown). Irrigation scheduling (except at C2) and rainfall were similar within individual experimental vineyard blocks with vines on both granite- and shale-derived soils. Furthermore, irrigation scheduling and rainfall were not expected to affect the vine water status (for vines on granite and shale-derived soils) within an experimental vineyard block in a different manner, thus not recorded in detail for this study.

At S1, leaf water potentials (2006/2007) indicated that vines on granite-derived soils were apparently slightly more stressed than those on shale-derived soils (Fig. 4.2a). In the 2007/2008 season the Sauvignon blanc vines on granite-derived soils were again apparently more stressed, but not just before harvest (Fig. 4.2b). The granite-derived soils at S1 had a lower water holding capacity than the shale-derived soils (refer to section 4.4.1). This may put more emphasis on the soil water regime (which is indirectly determined by geology) of a specific soil, rather than on geology as recently reviewed by Maltman (2008). In addition, the granite-derived soils at S1 had less fine roots in the deeper soil layers and a lower density of medium roots than the shale-derived soils (refer to section 4.4.1). Furthermore, although not indicated by the canopy density measurements in this study, a higher water stress may have been as a result of a larger canopy as indicated by Agenbach (2006).

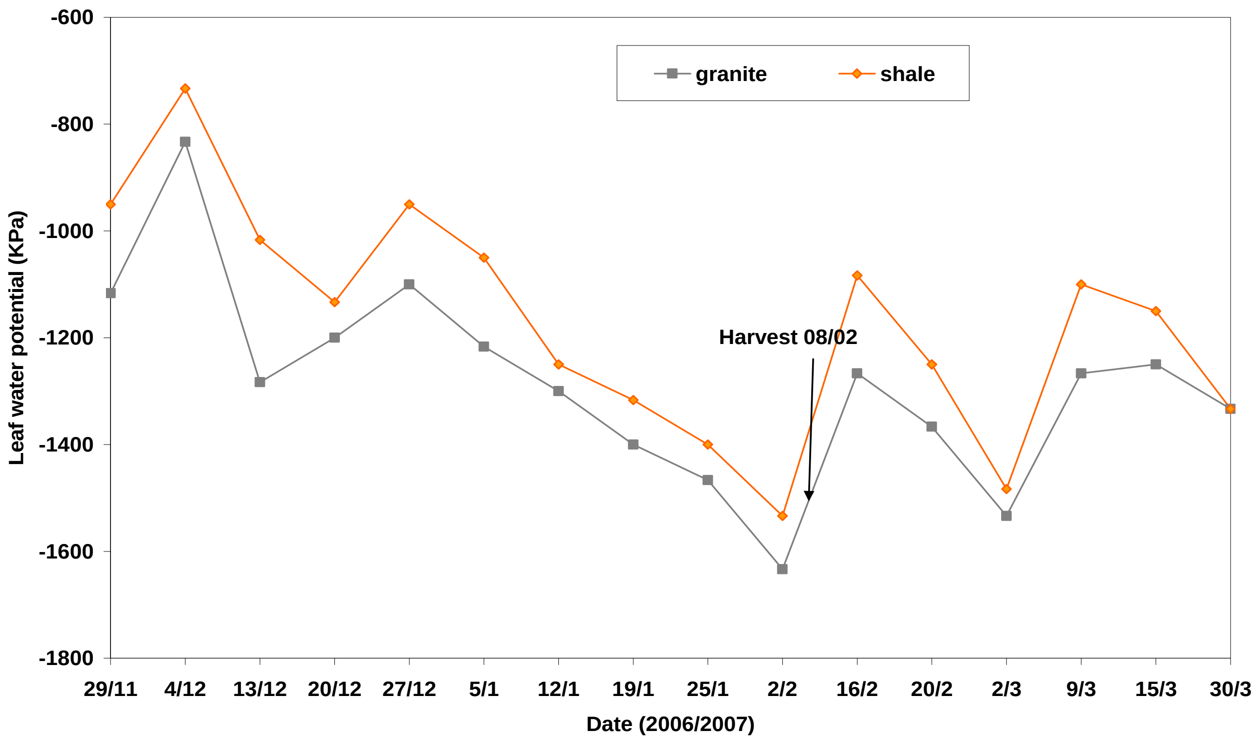

Figure 4.2a Midday leaf water potential (ψ_{leaf}) during the 2006/2007 season of Sauvignon blanc vines on granite- and shale-derived soils at S1.

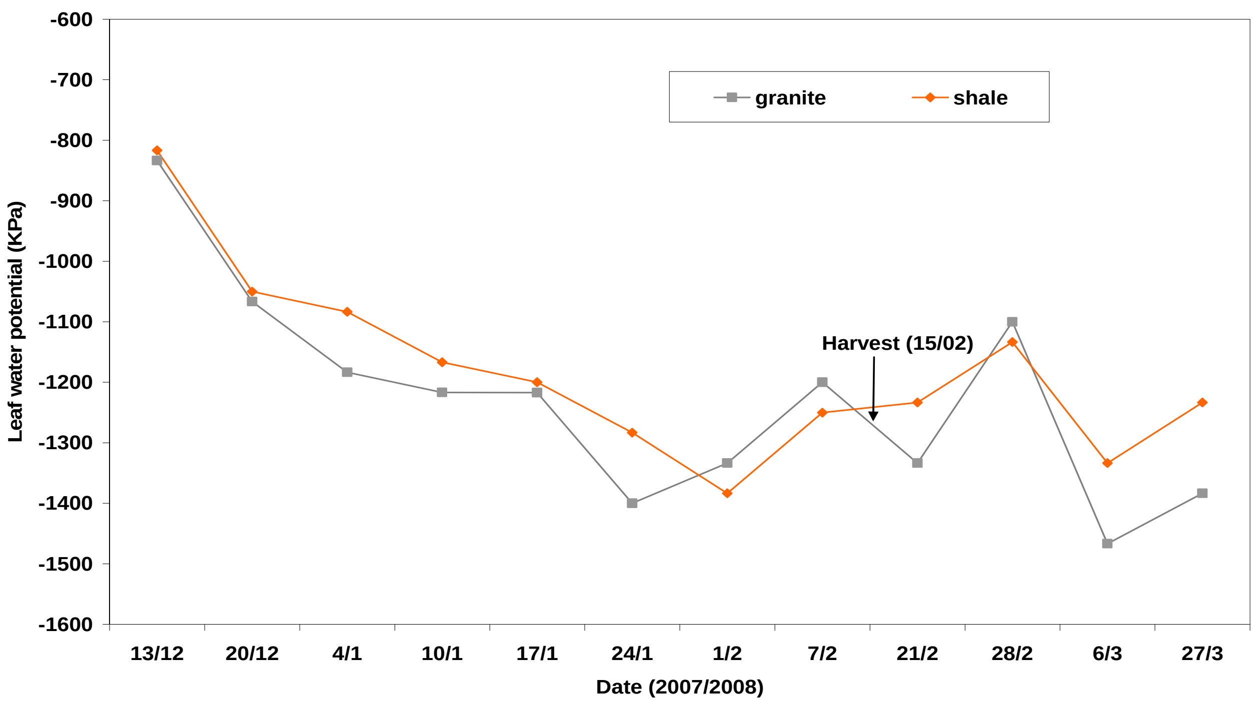

Figure 4.2b Midday leaf water potential (ψ_{leaf}) during the 2007/2008 season of Sauvignon blanc vines on granite- and shale-derived soils at S1.

At C2, in general, vines on shale-derived soils appeared more water stressed than those on granite-derived soils in the 2006/2007 season (Fig. 4.3a). However, this pattern was only observed from the beginning till the end of January in the 2007/2008 season (Fig. 4.3b).

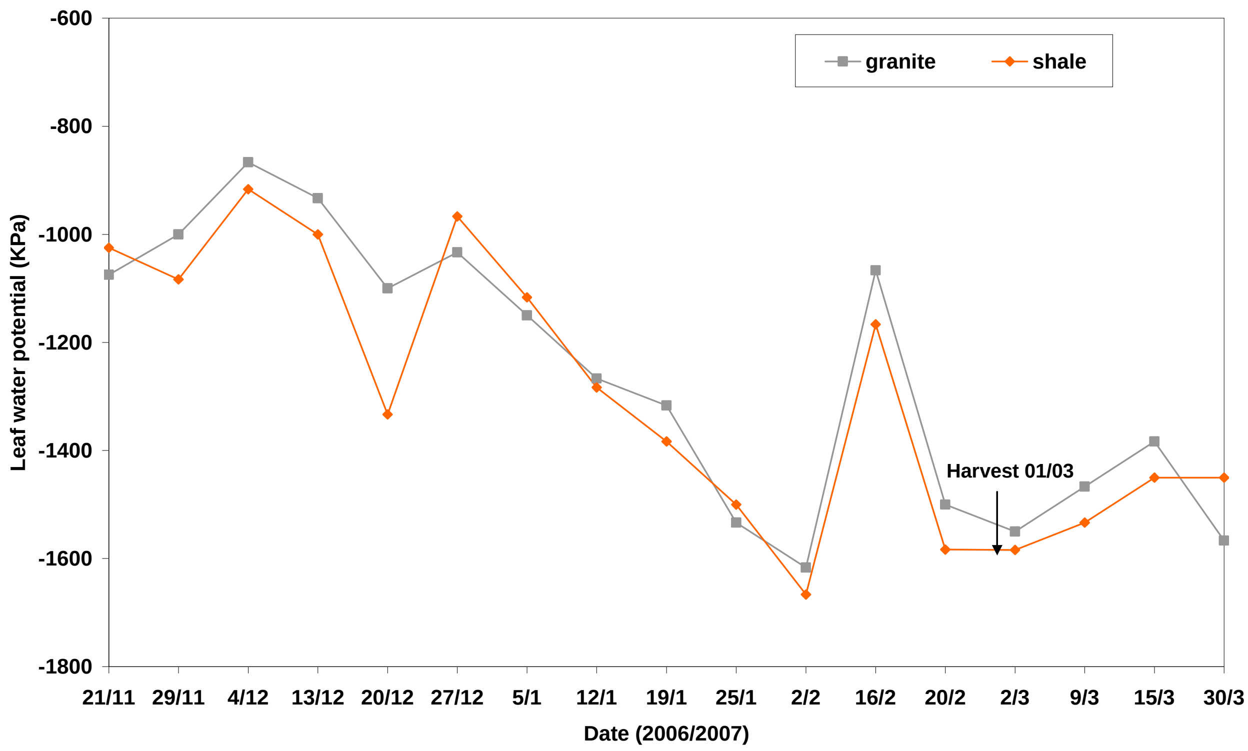

Figure 4.3a Midday leaf water potential (ψ_{leaf}) during the 2006/2007 season of Cabernet Sauvignon vines on granite- and shale-derived soils at C2.

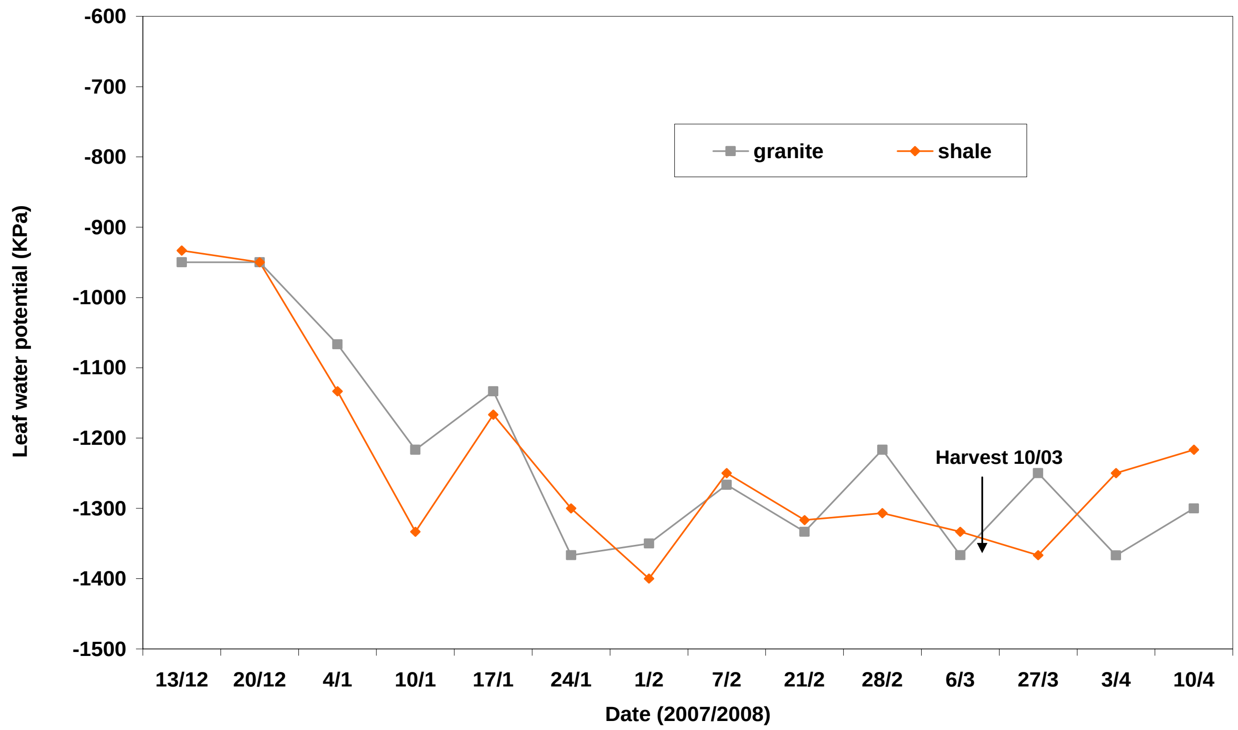

Figure 4.3b Midday leaf water potential (ψ_{leaf}) during the 2007/2008 season of Cabernet Sauvignon vines on granite- and shale-derived soils at C2.

At S2, in the beginning of the 2006/2007 season, vines on shale-derived soils appeared slightly more stressed than those on granite-derived soils, but the opposite was observed before the ripening period (Appendix 4B, Fig. 4.1a). In the 2007/2008 season, the opposite occurred i.e. vines on granite-derived soils appeared slightly more stressed than those on shale-derived soils at the beginning of the season, but the opposite was observed before the ripening period (Appendix 4B, Fig. 4.1b). At C1, there were no differences observed between soils in the 2006/2007 season (Appendix 4B, Fig. 4.2a). In the 2007/2008 season, Cabernet Sauvignon vines on shale-derived soils seemed to have been subjected to higher water stress than those on granite-derived soils from the beginning till the end of February, but the opposite occurred just before harvest (Appendix 4B, Fig. 4.2b). For this study, seasonal effects seemed to have affected the vine water status more than the geological differences in the soil. It was only at one site (S1), where levels of water stress seemed to have been indirectly affected by geological differences in the soils. No clear patterns were observed, for the rest of the sites.

4.5 CONCLUSIONS

The method and efficiency of physical soil preparation, together with chemical amelioration before planting seemed to have affected root distribution more than geology. However, the vine water status may reflect the efficiency of the root systems and the soil water status, which may have been indirectly affected by geological differences in the soil. The K nutritional status in the vines showed little relationship to the concentration of K in the soil, as the soil did not contain excessive amounts of K. Even though the soils originated from specific parent materials (granite and shale), intensive weathering, mixing of parent materials and fertilisation altered the physical and chemical composition of the parent material to such an extent that they were no longer easily recognisable. The soils in this study had adequate amounts of K, but it was not high enough to be highly reflected in either leaf blades or berry juice. Furthermore, vineyard practices (especially irrigation and fertilisation) and seasonal effects also contributed to masking the effects of geology on the K nutritional status in these vineyards. Due to the mixing of parent materials as was observed in this study, a pot experiment, which will allow exclusion of some variables may be more effective than a field study (as in this study), in terms of quantifying the effect of geology on the K status in vineyards.

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Chapter 5

General discussion and conclusions

CHAPTER 5: GENERAL DISCUSSION AND CONCLUSIONS

5.1 INTRODUCTION

The aim of the study was to quantify the effect of different geological mother materials (shale and granite) on the nutrient supply (especially K) of the resulting soils, and also on the nutritional status (especially K) of vines grown on such soils, Other factors that may have contributed to the nutrient (especially K) uptake and distribution in the vine, were also monitored.

5.2 GENERAL DISCUSSION

Particle size analyses indicated that mixing of shale and granite, as well higher altitude sandstone parent materials occurred in the top soils, possibly as a result of colluviation. In the lower horizons, however, granite-derived soils contained significantly higher amounts of coarse sand than shale-derived soils, while the situation was reversed for the fine sand fraction. This pointed towards a relatively pure geological origin for the sub soils. The differences in particle size distribution may have affected the water holding capacity, with soil water contents generally being higher for shale- than for granite-derived soils. Clay mineralogy differed slightly between localities, but in general, kaolinite was the dominant mineral, whereas quartz and feldspar were sub-dominant for both shale- and granite-derived soils. From a mineralogical perspective both soil types were highly weathered, without significant differences.

The Q/I parameters, potential buffering capacity of K (PBC^K) and equilibrium activity ratio of K (AR^K) showed no consistent relationship with geological differences. This was disappointing, as it was believed that this method would clearly indicate differences in the ability of these two soil types to supply K. However, shale-derived soils contained higher concentrations of total K, while granite-derived soils tended to have higher levels of soluble K, suggesting that the latter may have a higher ability to release K. The effects of geology on the nutritional status (especially K) of these two soil types may also have been masked by factors such as intensive weathering, soil preparation, high rainfall and irrigation.

Vines on shale-derived soils tended to experience less water stress, at least for one locality. Potassium concentrations in the leaf blades of granite-derived soils always tended higher. Concentrations of juice K were more affected by seasonal differences than by geology, but this was not always reflected in the pH values. Geology did not affect the K nutritional status as reflected by leaf and juice analyses of the Sauvignon blanc and Cabernet Sauvignon grapevines, in a consistent manner over the two seasons. However, there were some noticeable tendencies during specific seasons. On account of vines being planted on shale- and granite-derived soils within the same block, this exposed to similar soil preparation, irrigation, canopy management strategies and climatic conditions, it is highly probable that all these factors may have masked the effect of geology on the K status of soils and especially on juice K concentration.

5.3 PERSPECTIVE AND FUTURE RESEARCH

It is possible that style/quality of wines from shale- and granite-derived soils may differ, provided that all other factors are identical. Even though no major differences in juice composition could be identified in this study, it is of crucial importance that the effect of geology on wine quality should be further investigated. Quality differences (if any) between wines from shale- and granite-derived soils, may be possibly ascribed to the availability of K. However, due to the mixing of parent materials, as was observed in this study, it was not possible to clearly quantify the role of geology on the K availability in vineyards. A pot experiment where there can be more control of variables involved rather than a field study may be more effective, in terms of quantifying the effect of geology on the K status in vineyards. Future research may focus on studying the hydrological properties of granite- and shale-derived soils (as they seem to be more related to the type of parent materials than the nutritional status) and the vine water status of the vines grown in these soils. This could be the first study (geology) where N (consistently higher in juice from shale- than granite-derived soils) has also been identified as an important factor. The uptake of K may possibly be impeded indirectly on shale-derived soils, due to N/K antagonism. On account of the important role of N during the fermentation process, higher N-levels in juice from shale-derived soils may also result in higher wine quality. This aspect needs further investigation.

5.4 CONCLUSIONS

Results indicated that the effect of geology on the K supply of the resulting soils and on vine K status can be masked by factors such as weathering age of rocks, mixing of parent materials, soil preparation, liming, fertilizer applications, irrigation and vineyard management practices. However, geology can affect vine performance, *inter alia* by determining particle size distribution, which in turn may affect water holding capacity and the vine water status. Furthermore, juice composition may be affected more by seasonal differences than by geology. The method and efficiency of physical soil preparation, together with chemical amelioration before planting seemed to have affected root distribution more than geology. However, the vine water status may reflect the efficiency of the root systems and the soil water status, which may have been indirectly affected by geological differences in the soil. The K nutritional status in the vines (berries) has a little relationship with the concentration of K in the soil, especially if the soil does not contain excessive amounts of K. Even though the soils originated from specific parent materials (granite and shale), intensive weathering, mixing of parent materials and fertilisation altered the physical and chemical composition of the parent material to such an extent that they were no longer easily recognisable. The soils in this study had adequate amounts of K which were not high enough to be reflected on either leaf blades or berry juice. Furthermore, vineyard practices (especially fertilisation) and seasonal effects also contributed to the masking of the effects of geology on the K nutritional status in these vineyards.

APPENDIX 3A

Table 3.1 Particle size distribution (%) of granite and shale soils at four localities in the Helderberg area.

Horizons	Clay		Silt		Medium sand	
	Granite	Shale	Granite	Shale	Granite	Shale
A	18.3 a	14.4 a	18.1 a	18.4 a	17.1 a	14.6 a
B1	25.1 a	21.7 a	18.2 a	20.3 a	13.2 a	9.65 a
B2	24.4 a	23.1 a	22.4 a	19.7 a	11.8 a	8.58 a

Values in the same row with different letters indicate differences (P ≤ 0.1).

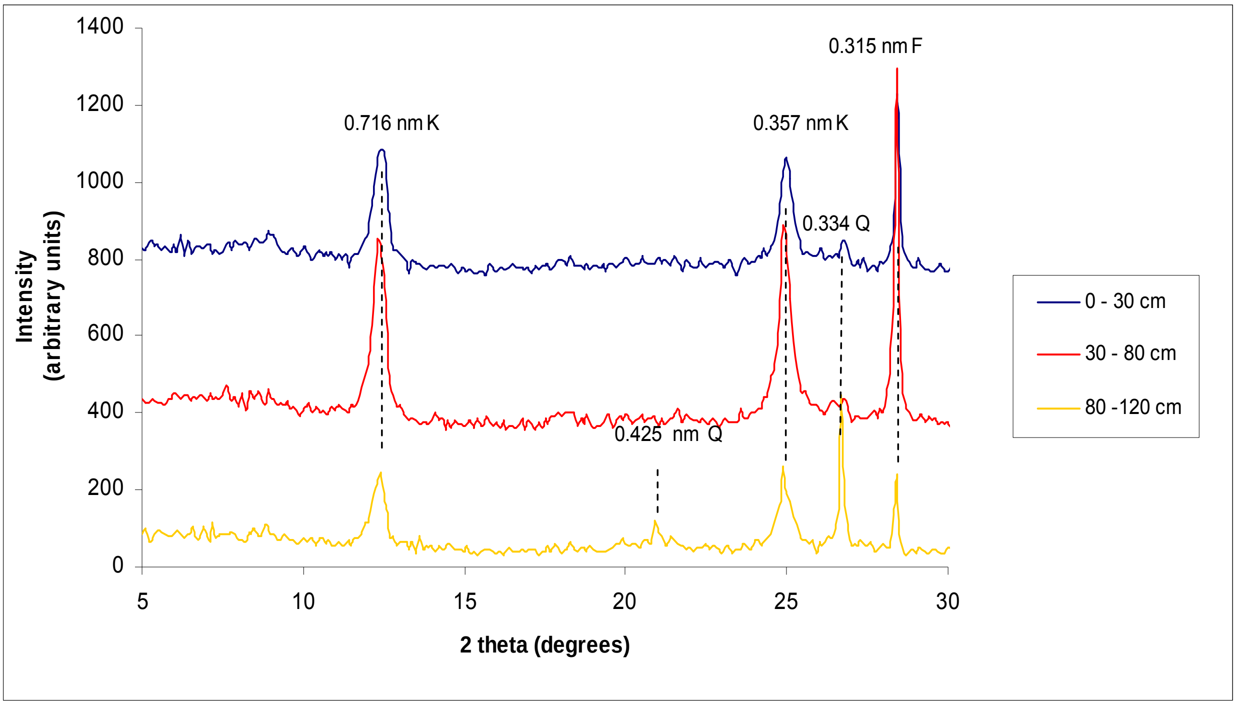

Figure 3.1a Effect of granite parent material on clay mineralogy of soils at S2 in Helderberg (F = feldspar, Q = quartz and K = kaolinite).

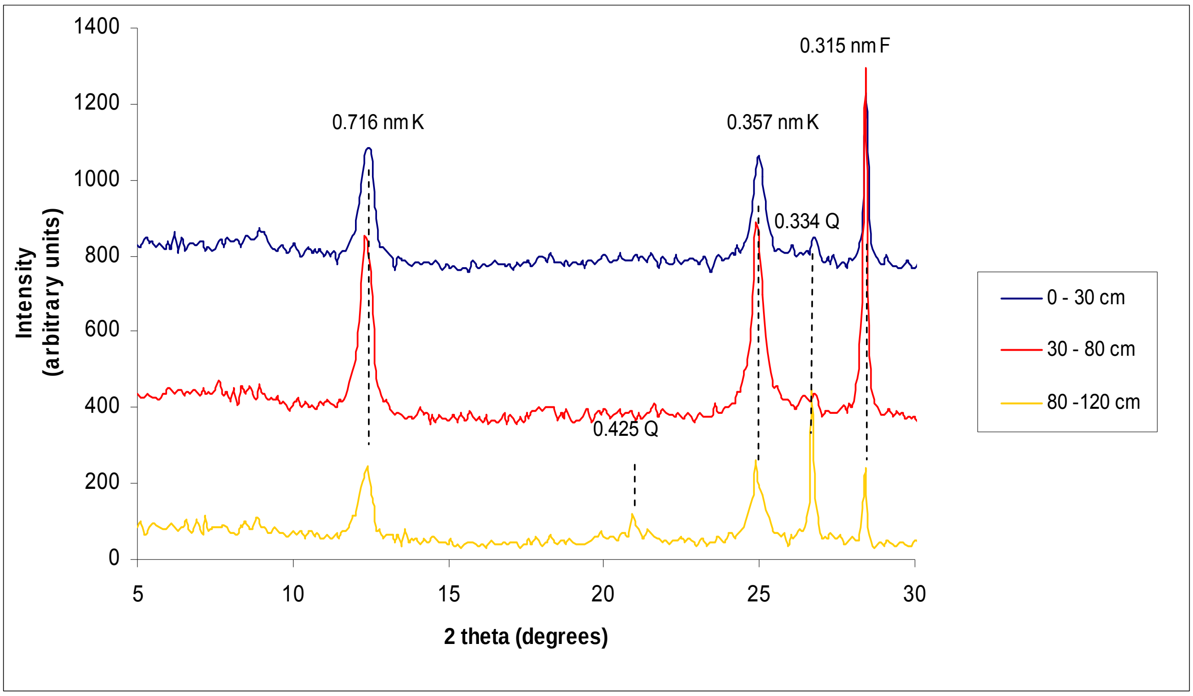

Figure 3.1b Effect of shale parent material on clay mineralogy of soils at S2 in Helderberg (F = feldspar, Q = quartz and K = kaolinite).

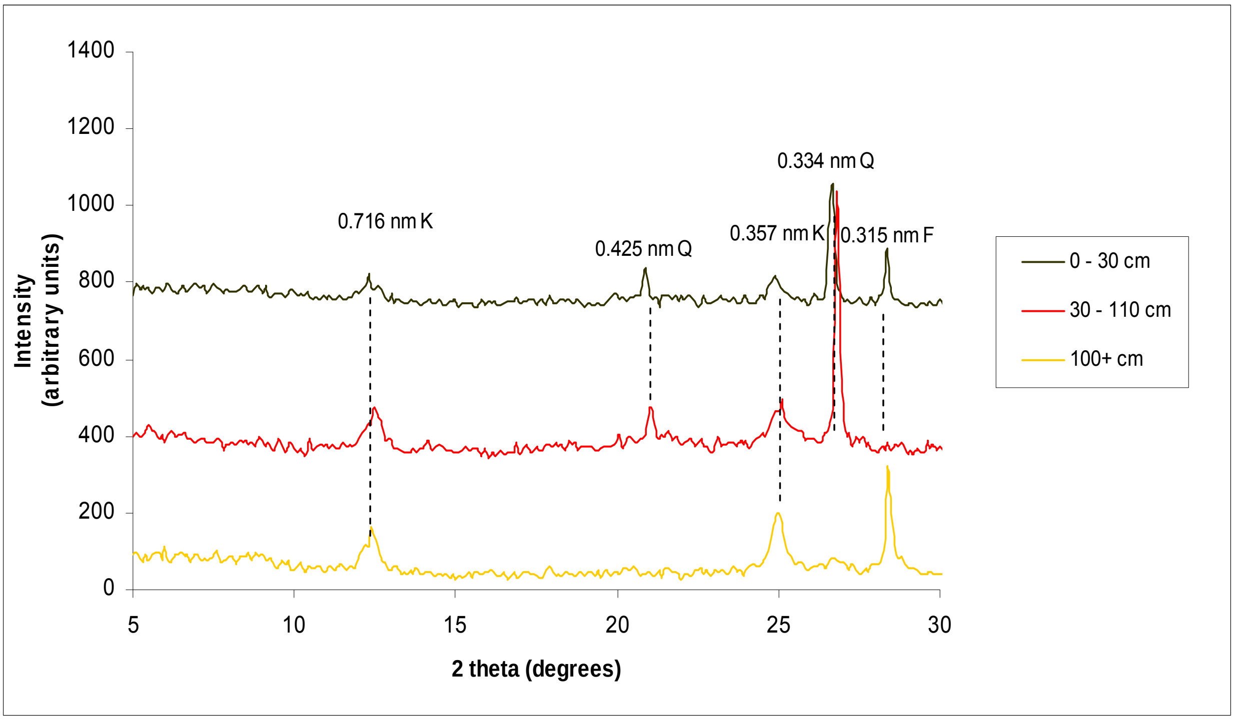

Figure 3.1c Effect of granite parent material on clay mineralogy of soils at C1, in Helderberg (F = feldspar, Q = quartz and K = kaolinite).

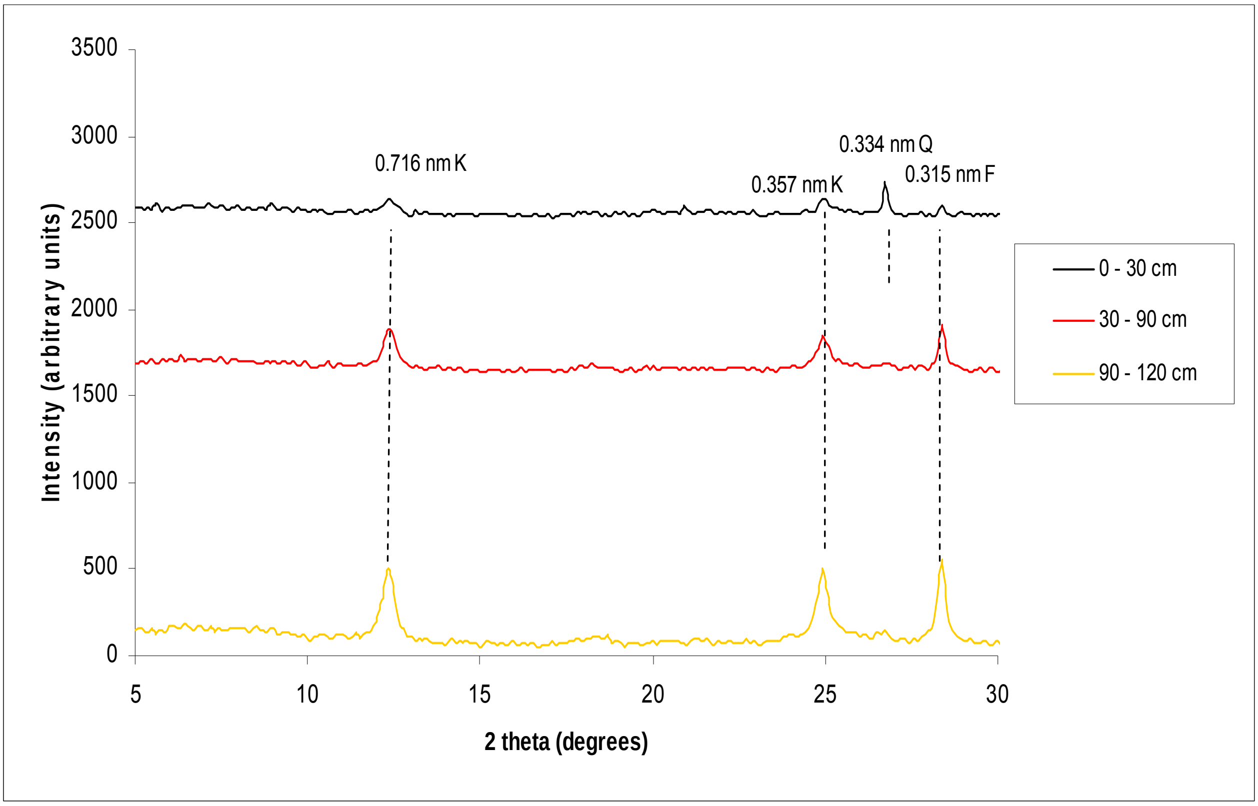

Figure 3.1d Effect of shale parent material on clay mineralogy of soils at C1 in Helderberg (F = feldspar, Q = quartz and K = kaolinite).

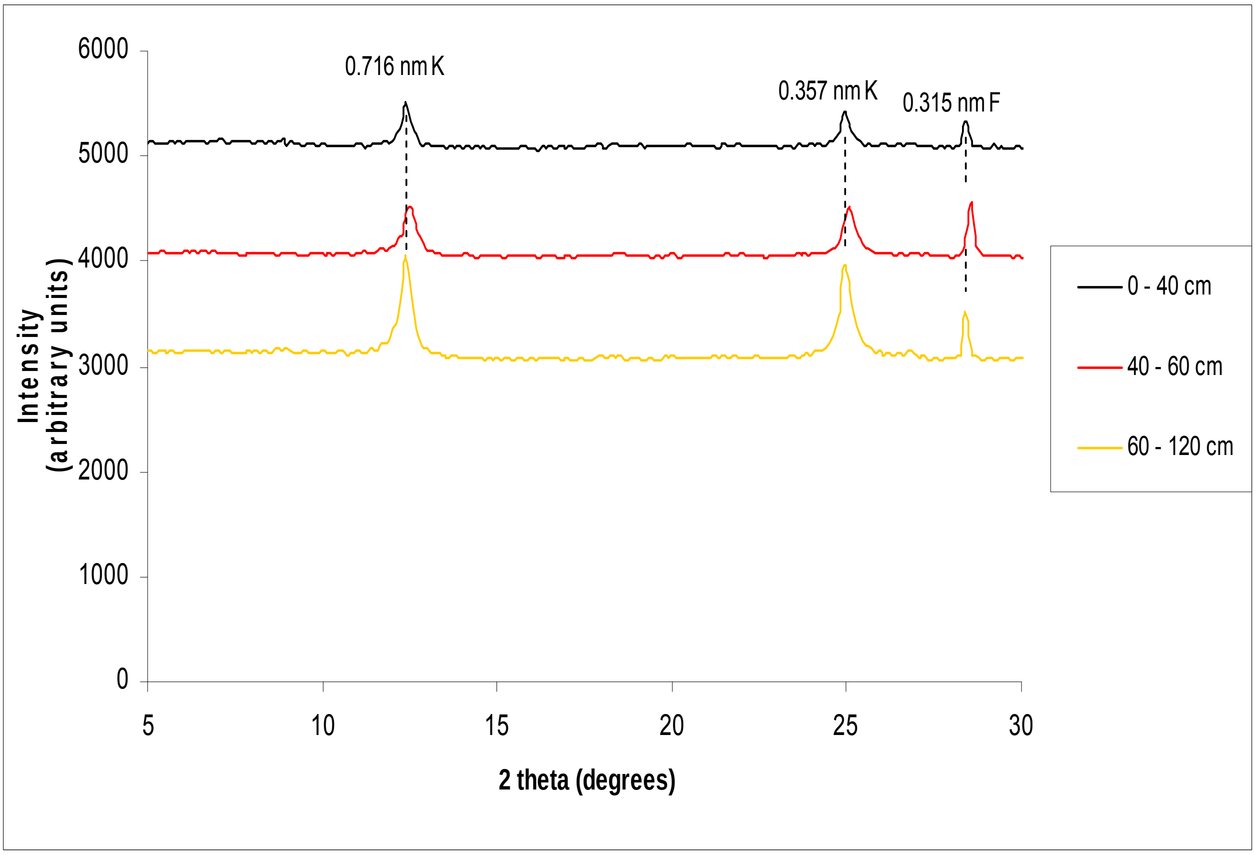

Figure 3.1e Effect of granite parent material on clay mineralogy of soils at C2 in Helderberg (F = feldspar and K = kaolinite).

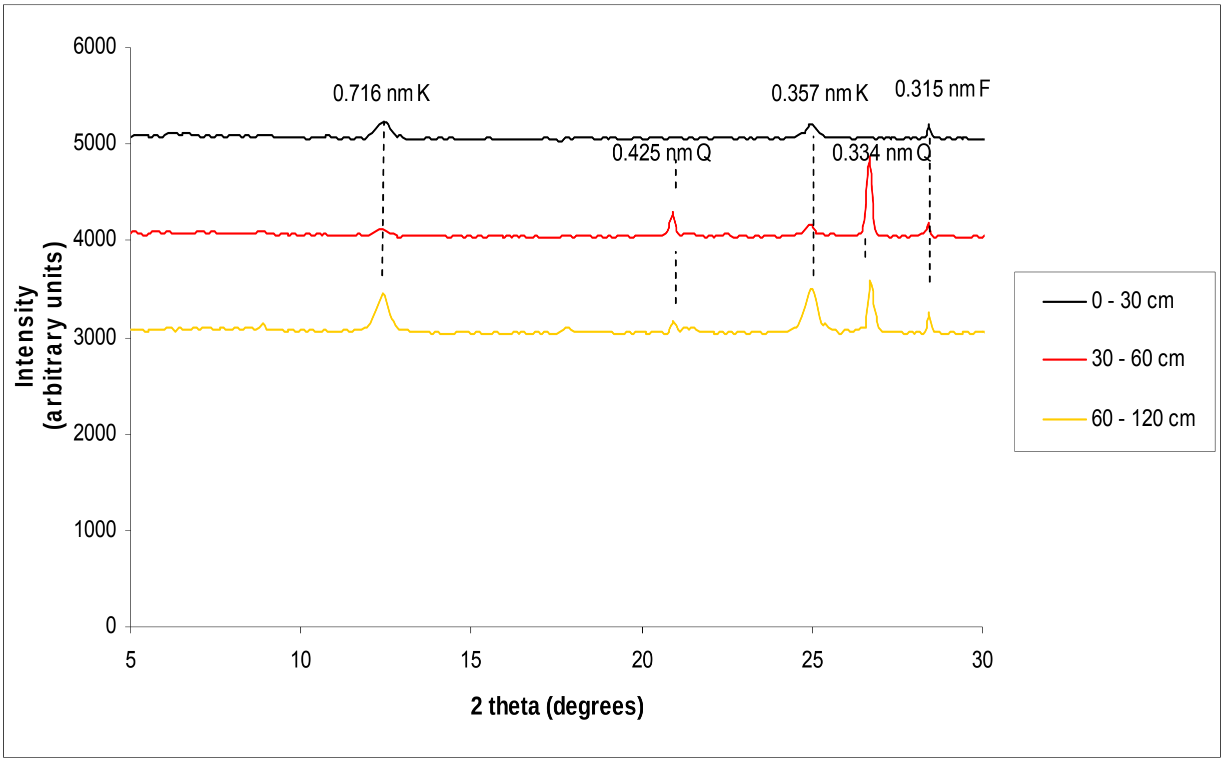

Figure 3.1f Effect of shale parent material on clay mineralogy of soils at C2 in Helderberg (F = feldspar, Q = quartz and K = kaolinite).

APPENDIX 3B

Table 3.1a Mean values of different forms of K from granite- and shale-derived soils from Sauvignon blanc (S1, S2) and Cabernet Sauvignon (C1, C2) vineyards.

Experimental vineyard	Horizon	Exchangeable K ($cmol_c$ kg^{-1})		Soluble K (mg ℓ^{-1})		Total K (mg kg^{-1})	
		Granite	Shale	Granite	Shale	Granite	Shale
S1	A	0.40	0.27	5.77	4.56	322	388
	B1	0.21	0.07	3.48	1.44	181	455
	B2	0.13	0.06	2.18	1.55	94	362
S2	A	0.58	0.86	7.34	8.39	796	1186
	B1	0.42	0.47	5.44	3.91	717	983
	B2	0.27	0.31	3.86	2.22	571	872
C1	A	0.31	0.37	3.56	5.67	555	832
	B1	0.21	0.22	2.81	2.41	530	722
	B2	0.13	0.16	1.40	2.28	403	665
C2	A	0.43	0.36	7.07	5.67	529	601
	B1	0.26	0.16	3.41	2.41	438	414
	B2	0.13	0.06	1.58	1.40	404	72.7

Table 3.1b Effect of locality on exchangeable K in the Sauvignon blanc (S1, S2) and Cabernet Sauvignon (C1, C2) vineyards.

Experimental plot	Horizons	Exchangeable K (cmol$_c$ kg^{-1})
S1	A	0.34 b
	B1	0.15 b
	B2	0.096 b
S2	A	0.72 a
	B1	0.45 a
	B2	0.29 a
C1	A	0.38 b
	B1	0.21 b
	B2	0.15 b
C2	A	0.39 b
	B1	0.21 b
	B2	0.095 b

Values in the same column (for the same horizons) with different letters indicate differences ($P \leq 0.1$).

APPENDIX 3C

Table 3.1a Mean pH (H_2O) of Sauvignon blanc (S1, S2) and Cabernet Sauvignon (C1, C2) vineyard soils in the Helderberg area.

Horizons	S1	S2	C1	C2
A	6.65 a	6.00 c	6.38 ab	6.18 bc
B1	6.52 a	5.68 b	6.37 a	6.38 a
B2	6.50 a	5.08 b	6.48 a	6.39 a

Values in the same row with different letters indicate differences ($P \leq 0.05$).

Table 3.1b Mean pH (H_2O) of granite- and shale-derived soils at each locality (S1, S2, C1 and C2) in the Helderberg area.

Horizons	S1		S2		C1		C2	
	Granite	Shale	Granite	Shale	Granite	Shale	Granite	Shale
A	6.70	6.60	5.97	6.05	6.50	6.27	6.20	6.17
B1	6.63	6.40	5.52	6.50	6.42	6.32	6.32	6.43
B2	6.62	6.38	4.72	5.43	6.52	6.45	6.42	6.37

Table 3.2a Mean Calcium concentrations ($cmol_c\,kg^{-1}$) in Sauvignon blanc (S1, S2) and Cabernet Sauvignon (C1, C2) vineyard soils in the Helderberg area.

Horizons	S1	S2	C1	C2
A	5.44 a	5.01 a	5.59 a	4.08 a
B1	2.36 a	3.36 a	3.18 a	1.68 a
B2	1.95 a	2.42 a	1.80 a	0.99 a

Values in the same row with different letters indicate differences (P ≤ 0.05).

Table 3.2b Effect of geology (granite and shale) on Calcium ($cmol_c\,kg^{-1}$) concentrations in Sauvignon blanc (S1, S2) and Cabernet Sauvignon (C1, C2) vineyard soils in the Helderberg area.

Horizons	S1		S2		C1		C2	
	Granite	Shale	Granite	Shale	Granite	Shale	Granite	Shale
A	4.84	6.03	3.67	6.35	7.06	4.13	4.41	3.74
B1	1.68	3.03	2.28	4.45	4.37	1.99	1.77	1.59
B2	1.46	2.43	1.84	2.99	2.31	1.29	1.06	0.91

Table 3.3a Mean cation exchange capacity ($cmol_c\,kg^{-1}$) in Sauvignon blanc (S1, S2) and Cabernet Sauvignon (C1, C2) vineyard soils in the Helderberg area.

Horizons	S1	S2	C1	C2
A	5.67 a	7.25 a	5.92 a	6.89 a
B1	4.86 a	6.16 a	5.59 a	5.61 a
B2	4.26 a	5.63 a	5.07 a	4.64 a

Values in the same row with different letters indicate differences (P ≤ 0.05).

Table 3.3b Effect of geology (granite and shale) on cation exchange capacity ($cmol_c\,kg^{-1}$) in Sauvignon blanc (S1, S2) and Cabernet Sauvignon (C1, C2) vineyard soils in the Helderberg area.

Horizons	S1		S2		C1		C2	
	Granite	Shale	Granite	Shale	Granite	Shale	Granite	Shale
A	5.97	5.37	5.97	8.54	6.14	5.70	6.34	7.43
B1	5.42	4.29	5.39	6.93	5.62	5.56	5.04	6.17
B2	4.70	3.82	5.17	6.09	4.78	5.37	4.54	4.74

Table 3.4a Mean organic Carbon content (%) in Sauvignon blanc (S1, S2) and Cabernet Sauvignon (C1, C2) vineyard soils in the Helderberg area.

Horizons	S1	S2	C1	C2
A	2.27 a	0.97 b	1.67 ab	2.32 a
B1	1.74 a	0.66 a	1.30 a	1.54 a
B2	1.15 a	0.92 a	1.34 a	0.69 a

Values in the same row with different letters indicate differences (P ≤ 0.1 for A-horizons and P ≤ 0.05 for both B1 and B2 horizons).

Table 3.4b Effect of geology (granite, shale) on organic C content (%) in Sauvignon blanc (S1, S2) and Cabernet Sauvignon (C1, C2) vineyard soils in the Helderberg area.

Horizons	S1		S2		C1		C2	
	Granite	Shale	Granite	Shale	Granite	Shale	Granite	Shale
A	2.32	2.23	1.01	0.92	1.91	1.44	1.83	2.82
B1	1.87	1.62	0.68	0.64	1.66	0.93	1.09	1.99
B2	1.47	0.83	0.44	1.41	1.46	1.23	0.77	0.61

Table 3.5 Mean total-N content (%) in Sauvignon blanc (S1, S2) and Cabernet Sauvignon (C1, C2) vineyard soils in the Helderberg area.

Horizons	S1	S2	C1	C2
A	0.15 a	0.09 b	0.11 ab	0.14 ab
B1	0.10 a	0.07 a	0.09 a	0.09 a
B2	0.07 a	0.09 a	0.08 a	0.05 a

Values in the same row with different letters indicate differences ($P \leq 0.1$ for A-horizons and $P \leq 0.05$ for both B-horizons).

APPENDIX 3D

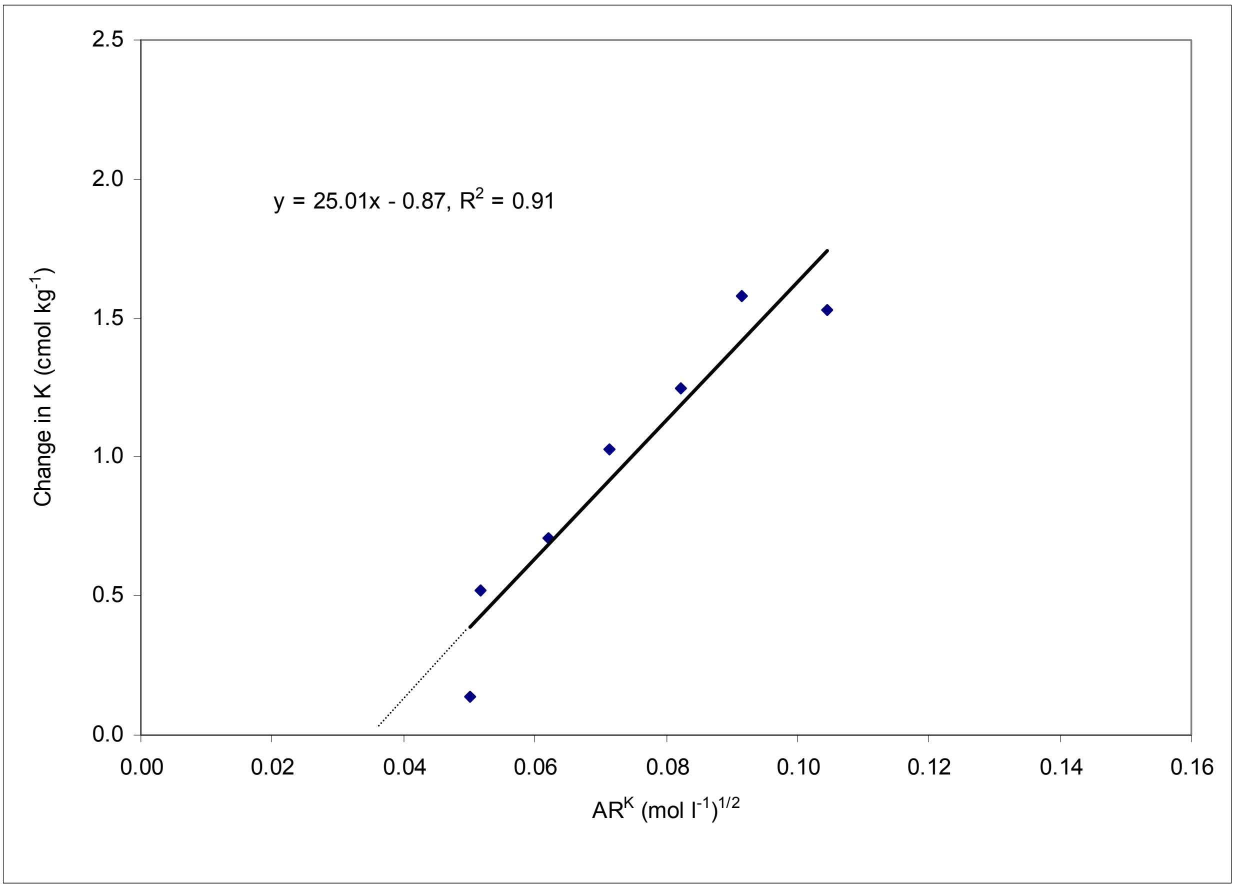

Figure 3.1a Potassium quantity/ intensity (Q/I) curve of the A-horizon shale-derived soils from a Cabernet Sauvignon vineyard (C1), AR^K represents the activity ratio for K and PBC^K (potential buffering capacity for K) = 25.01 cmol kg^{-1}. (mol $\ell^{-1})^{1/2}$.

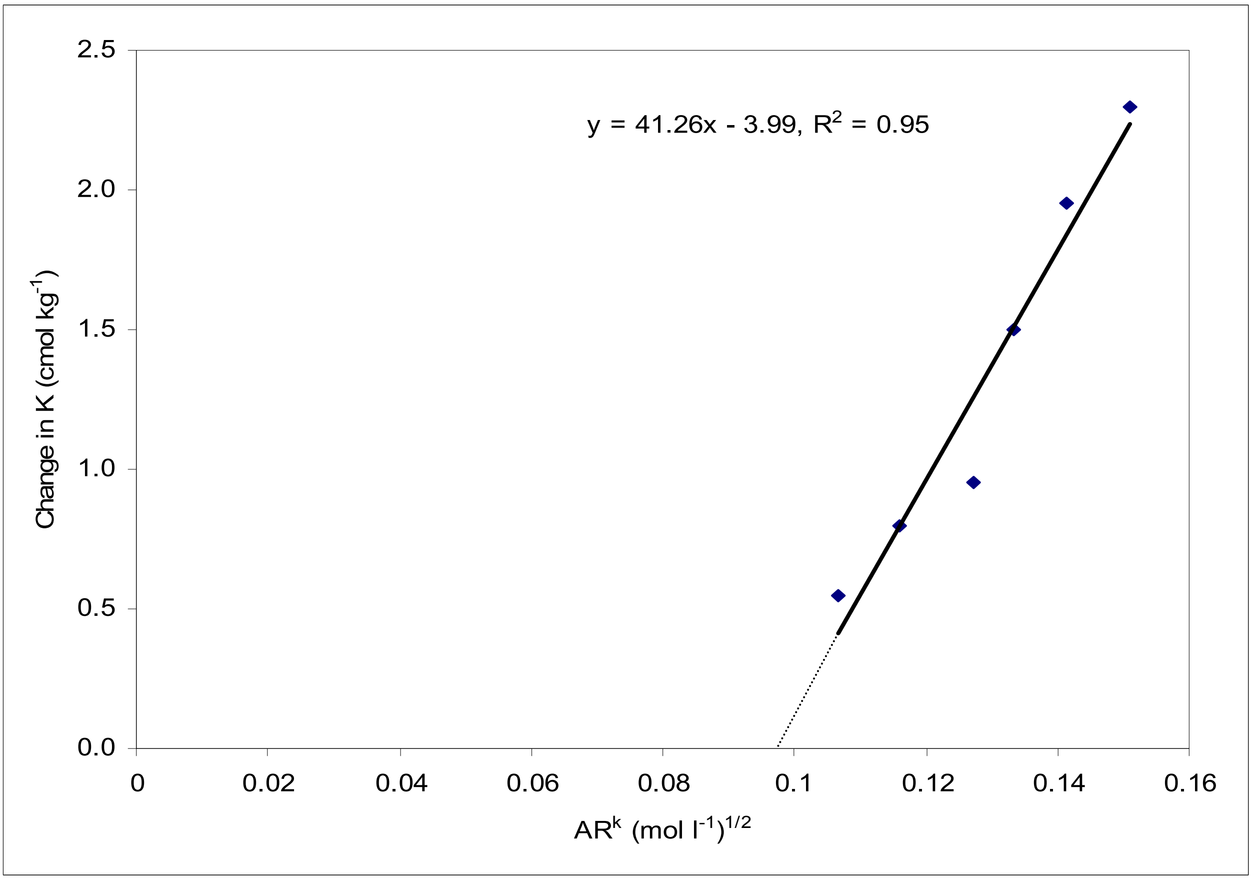

Figure 3.1b Potassium quantity/ intensity (Q/I) curve of the A-horizon granite-derived soils from a Cabernet Sauvignon vineyard (C1), AR^K represents the activity ratio for K and PBC^K (potential buffering capacity for K) = 41.26 cmol kg^{-1} . (mol ℓ$^{-1}$)$^{1/2}$.

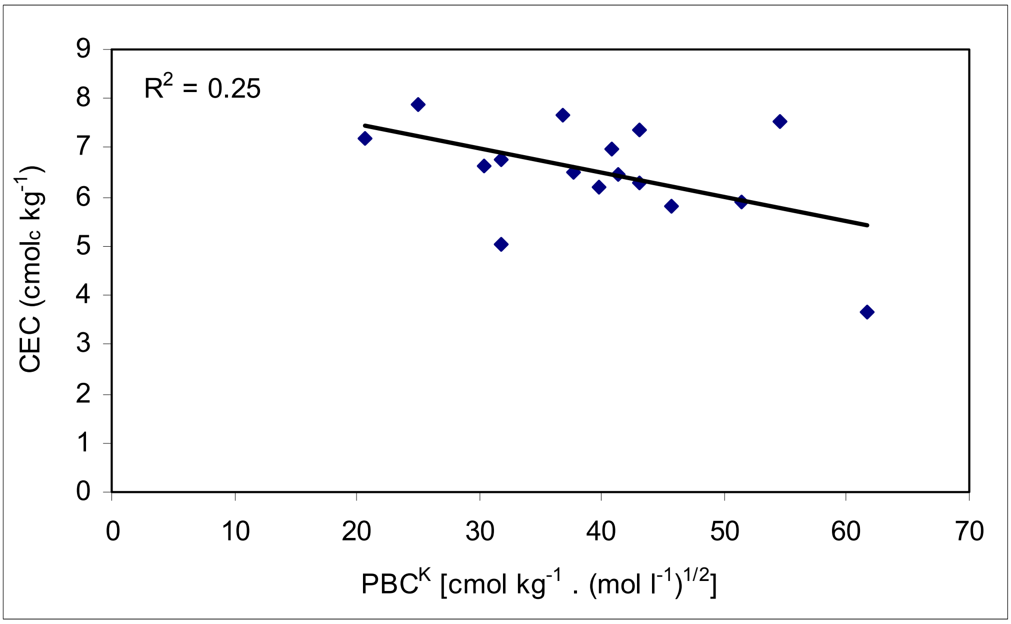

Figure 3.2 Cation exchange capacity and potential buffer capacity of A-horizon soils (granite- and shale-derived soils) from Cabernet Sauvignon vineyards (C1, C2).

APPENDIX 3E

Table 3.1 Soil water content at field capacity (-10 kPa) and permanent wilting point (-1500 kPa) for geologically different soils on Sauvignon blanc (S1, S2) and Cabernet Sauvignon (C1, C2) vineyards in the Helderberg area.

Experimental vineyard	Geology	Field capacity (g 100 g^{-1})			Permanent wilting point (g 100 g^{-1})		
		0-300 mm	300-600 mm	600-900 mm	0-300 mm	300-600 mm	600-900 mm
S1	Granite	26.43	24.49	25.19	14.49	12.34	12.70
	Shale	24.69	28.00	23.34	13.37	10.14	8.45
S2	Granite	*	*	16.47	*	*	10.26
	Shale	18.73	19.92	21.76	10.61	7.24	8.66
C1	Granite	(1)	18.62	23.56	(1)	8.54	13.06
	Shale	19.92	20.53	20.80	7.24	7.46	8.28
C2	Granite	21.60	23.58	31.70	9.83	9.74	16.93
	Shale	30.52	32.40	37.90	13.77	14.49	20.60

* Not available due difficulty in identifying reliable values for field capacity and permanent wilting point.

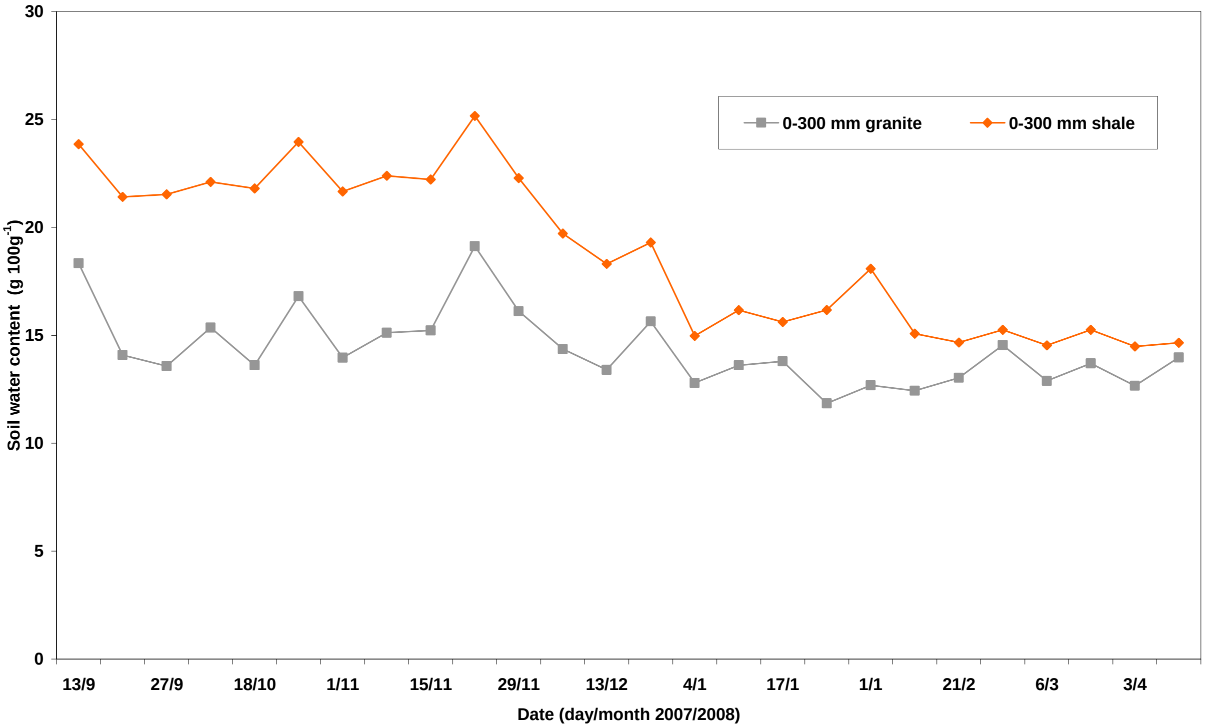

Figure 3.1a Soil water content during the 2007/2008 season for granite- and shale- derived soils (0-300 mm) in a Sauvignon blanc vineyard (S1) in Helderberg.

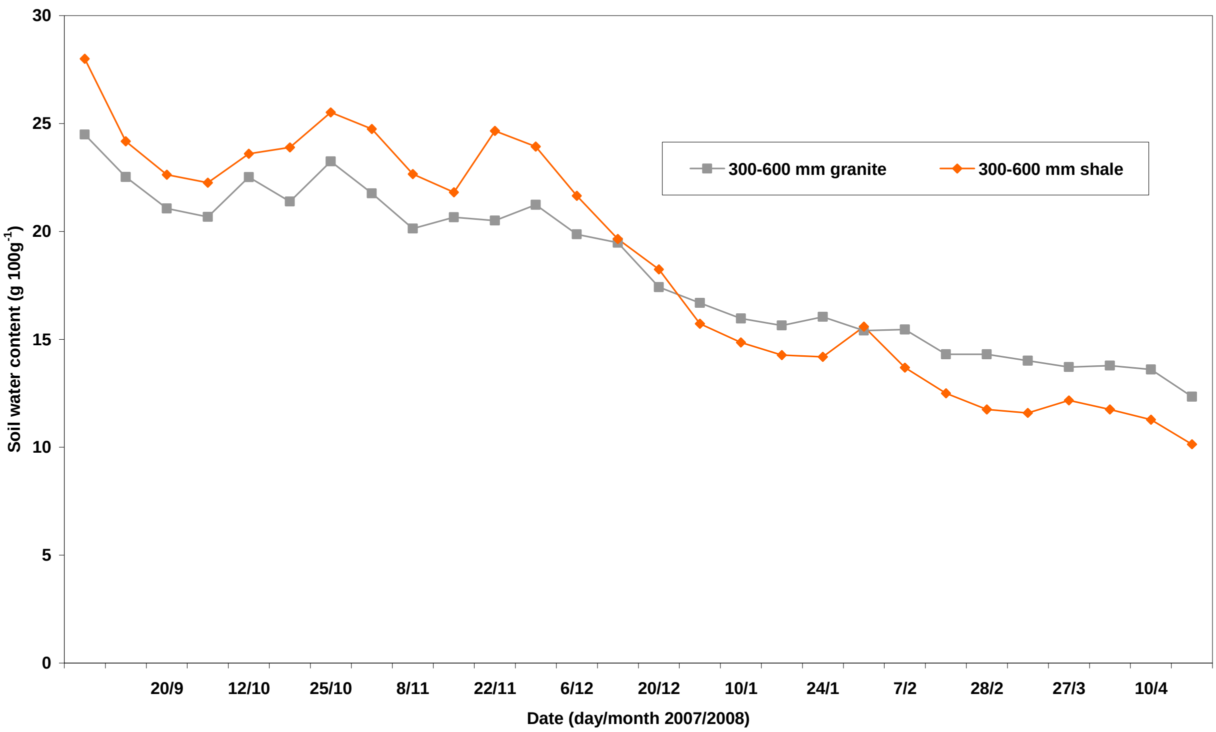

Figure 3.1b Soil water content during the 2007/2008 season for granite- and shale- derived soils (300-600 mm) in a Sauvignon blanc vineyard (S1) in Helderberg.

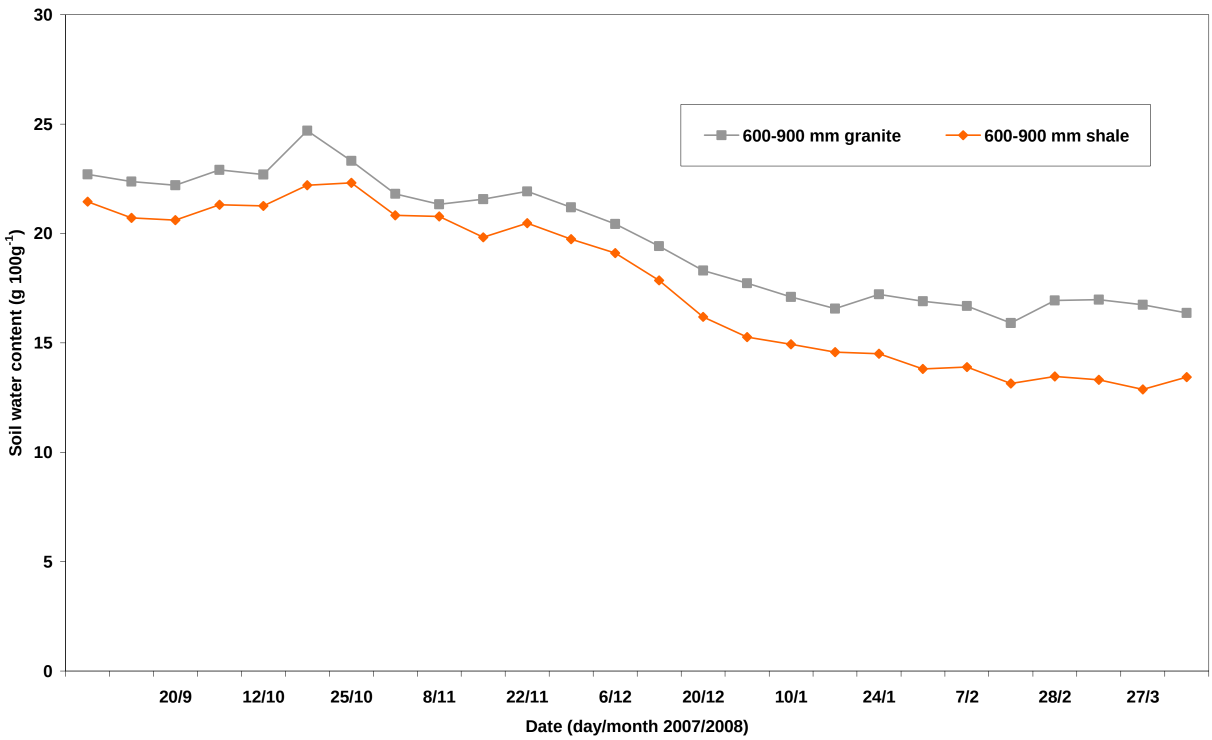

Figure 3.1c Soil water content during the 2007/2008 season for granite- and shale- derived soils (600-900 mm) in a Sauvignon blanc vineyard (S1) in Helderberg.

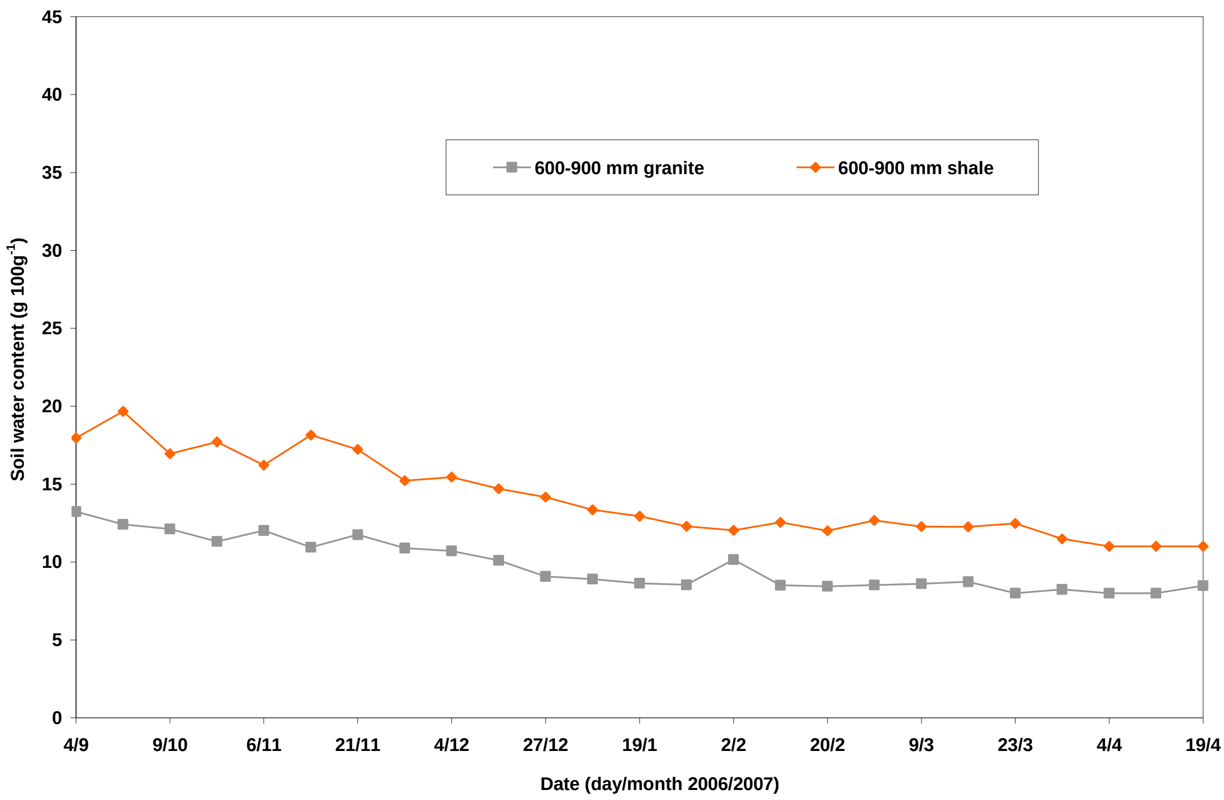

Figure 3.2a Soil water content during the 2006/2007 season for granite- and shale- derived soils (600-900 mm) in a Sauvignon blanc vineyard (S2) in Helderberg.

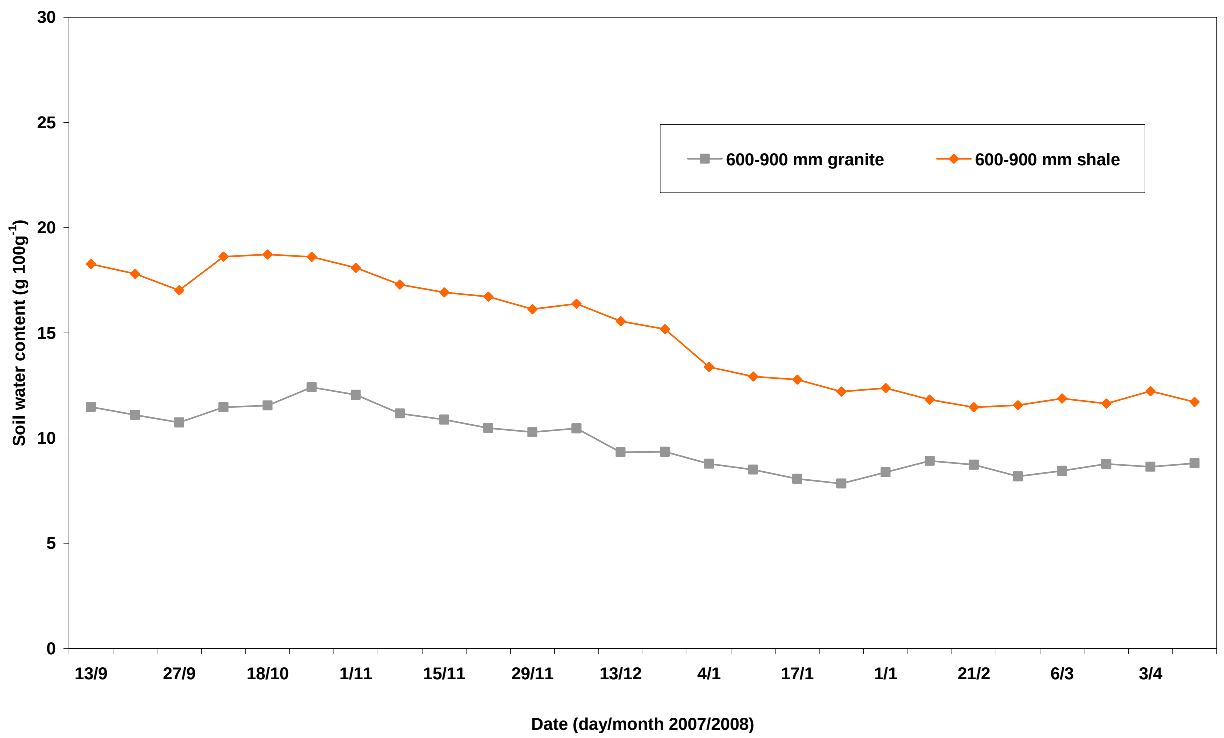

Figure 3.2b Soil water content during the 2007/2008 season for granite- and shale- derived soils (600-900 mm) in a Sauvignon blanc vineyard (S2) in Helderberg.

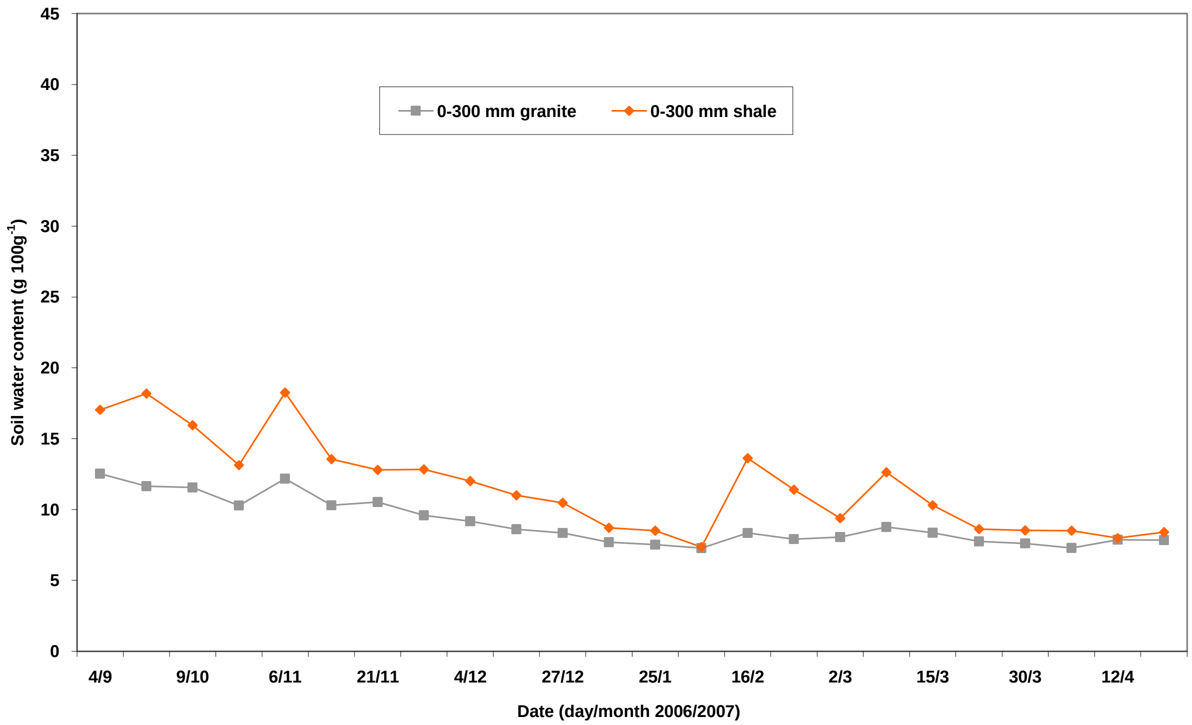

Figure 3.3a Soil water content during the 2006/2007 season for granite- and shale- derived soils (0-300 mm) in a Cabernet Sauvignon vineyard (C1) in Helderberg.

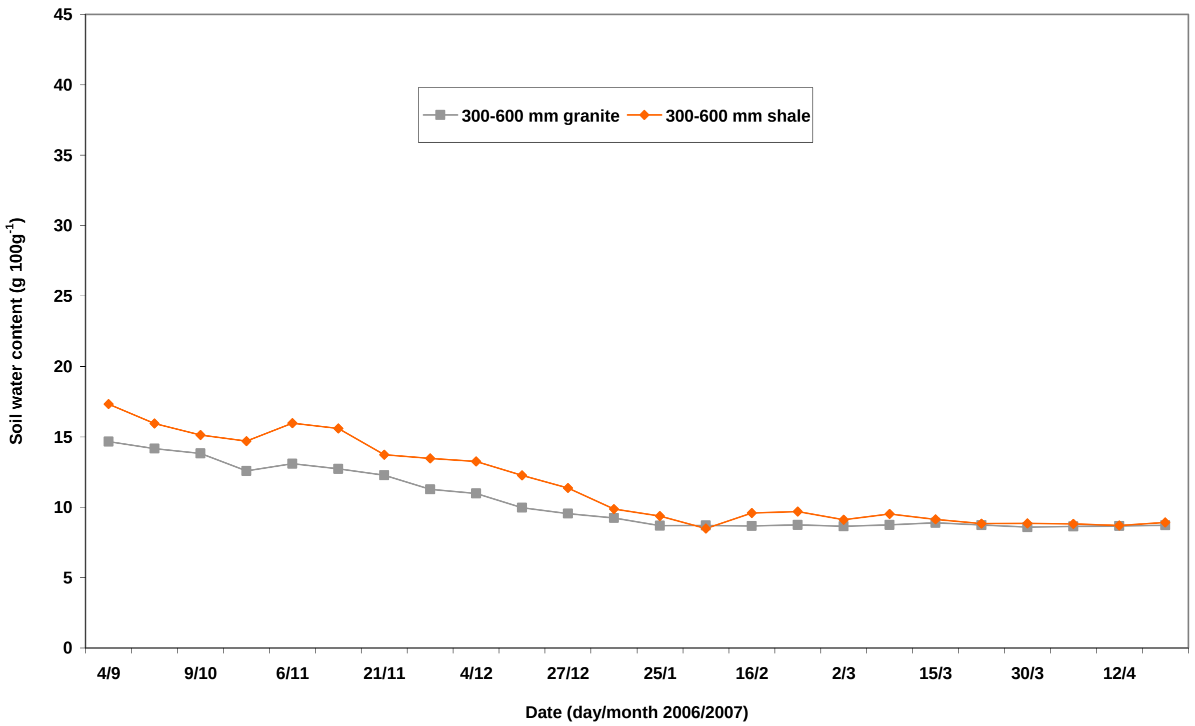

Figure 3.3b Soil water content during the 2006/2007 season for granite- and shale- derived soils (300-600 mm) in a Cabernet Sauvignon vineyard (C1) in Helderberg.

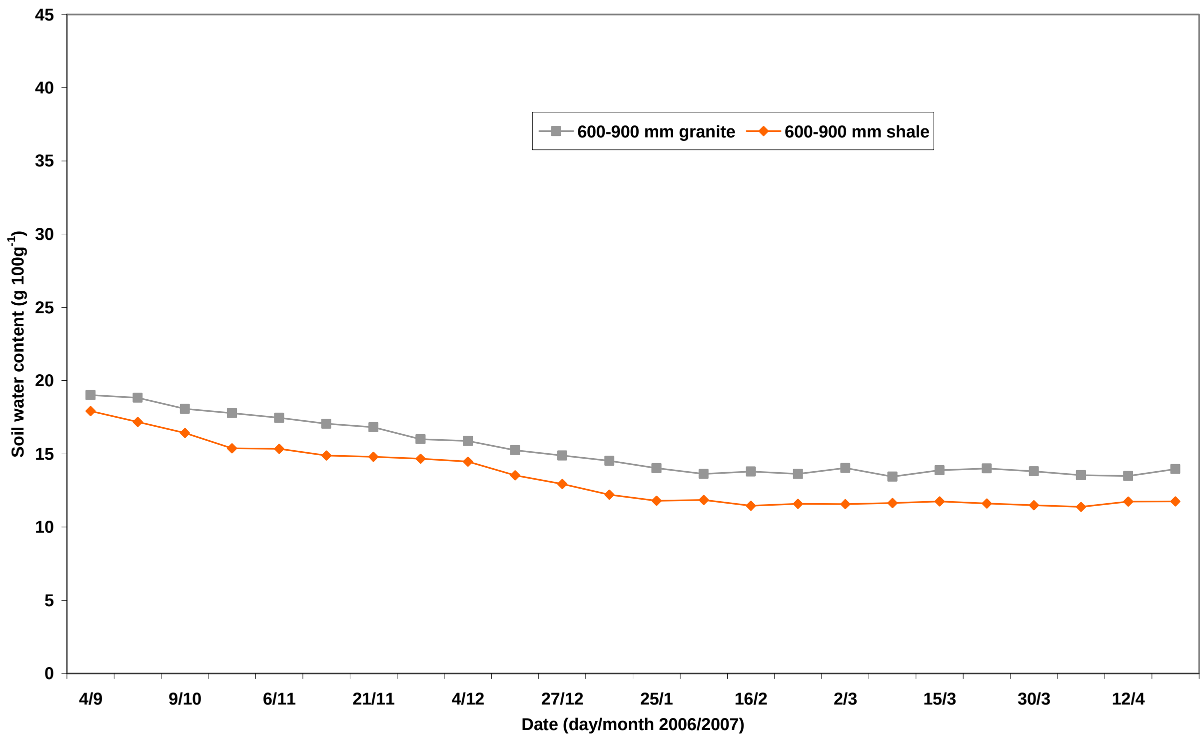

Figure 3.3c Soil water content during the 2006/2007 season for granite- and shale- derived soils (600-900 mm) in a Cabernet Sauvignon vineyard (C1) in Helderberg.

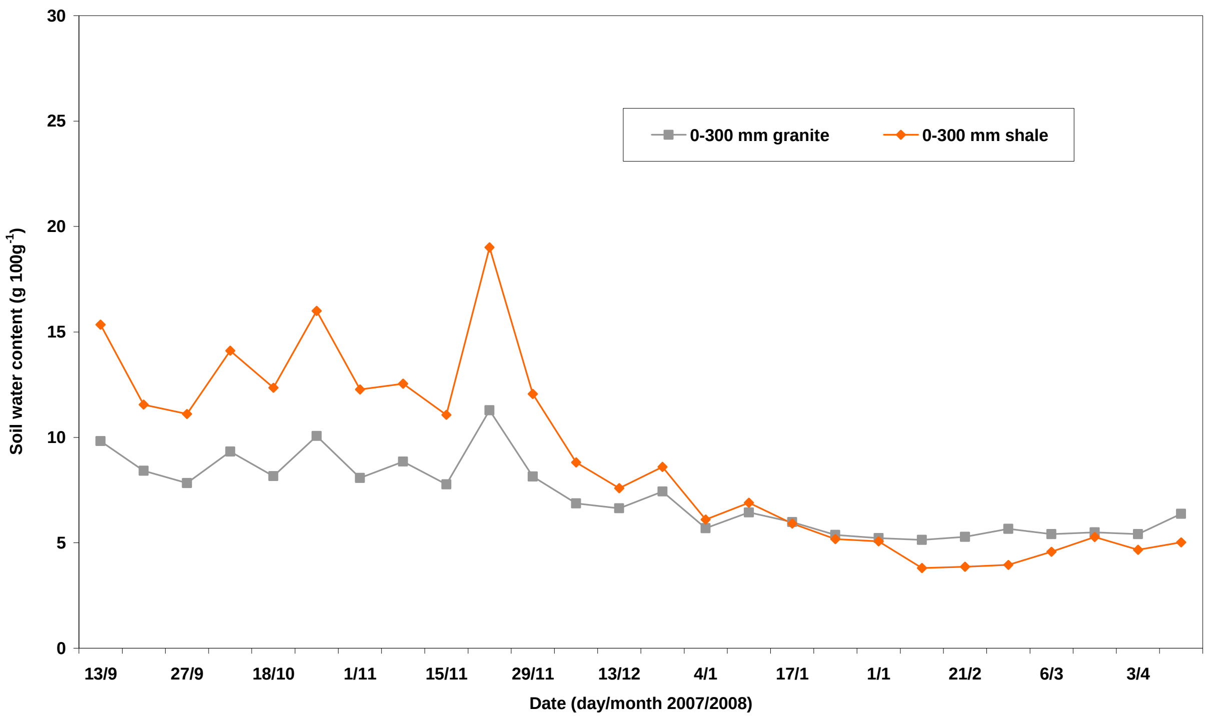

Figure 3.3d Soil water content during the 2007/2008 season for granite- and shale- derived soils (0-300 mm) in a Cabernet Sauvignon vineyard (C1) in Helderberg.

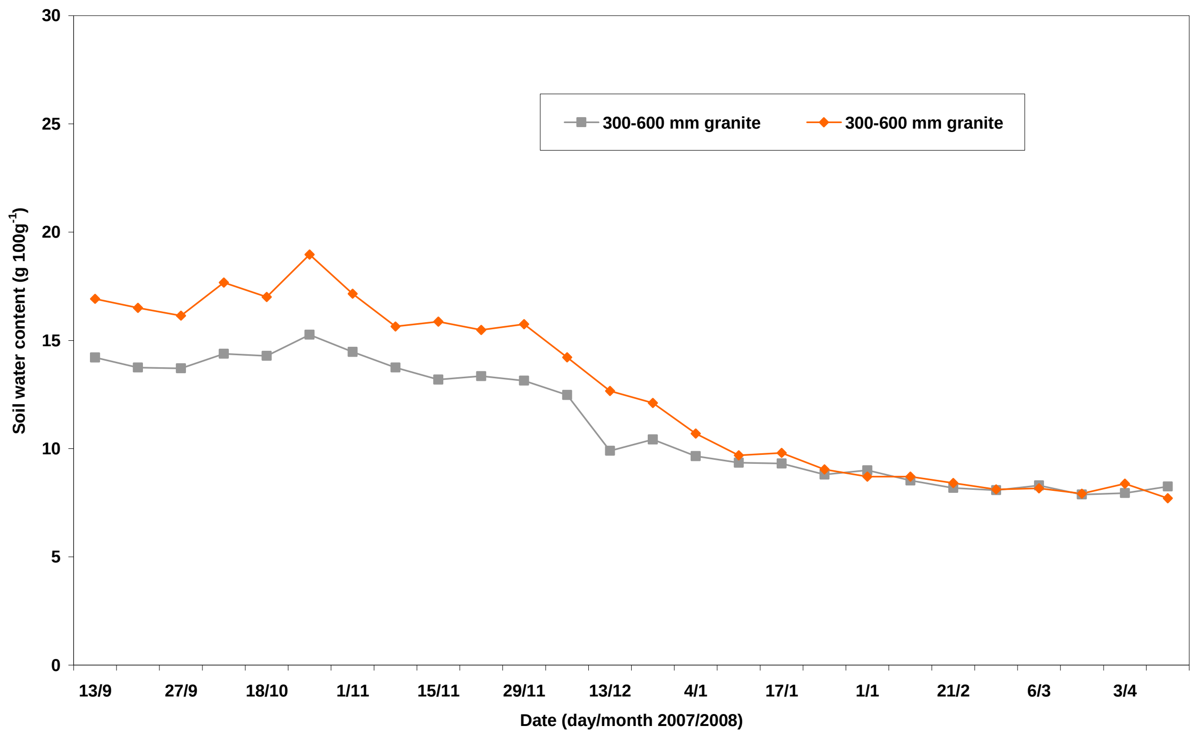

Figure 3.3e Soil water content during the 2007/2008 season for granite- and shale- derived soils (300-600 mm) in a Cabernet Sauvignon vineyard (C1) in Helderberg.

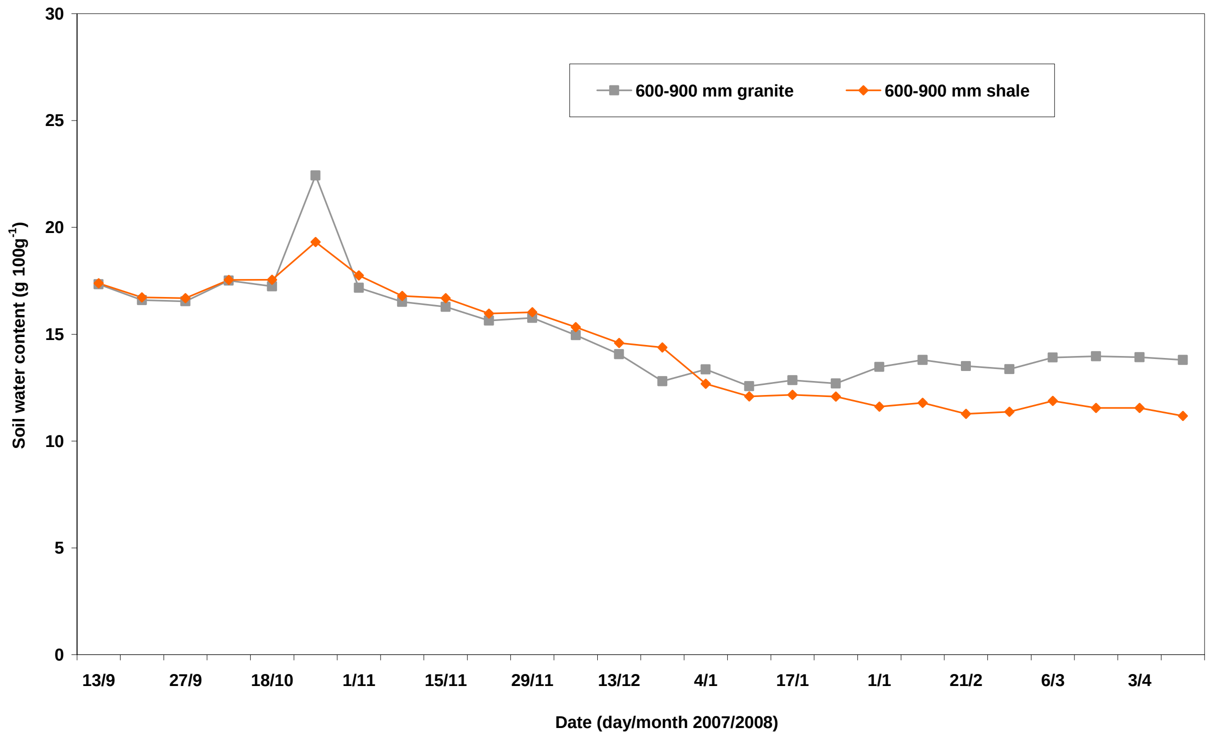

Figure 3.3f Soil water content during the 2007/2008 season for granite- and shale- derived soils (600-900 mm) in a Cabernet Sauvignon vineyard (C1) in Helderberg.

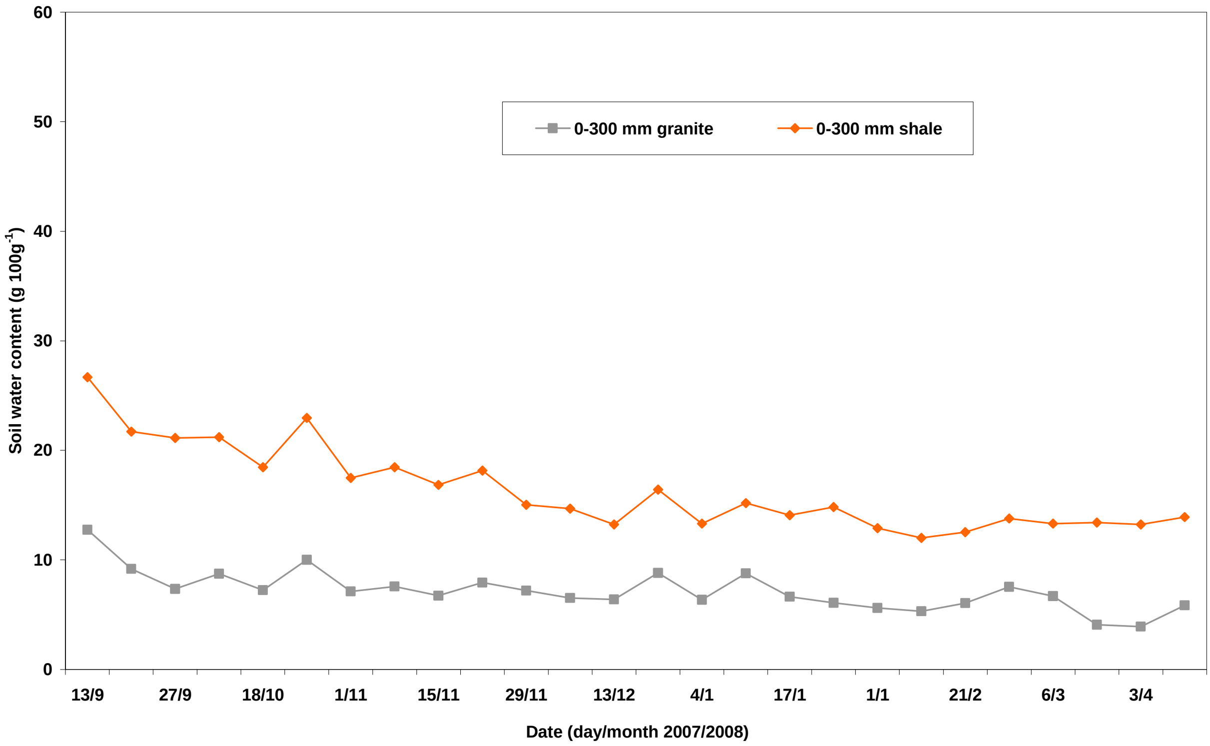

Figure 3.4a Soil water content during the 2007/2008 season for granite- and shale- derived soils (0-300 mm) in a Cabernet Sauvignon vineyard (C2) in Helderberg.

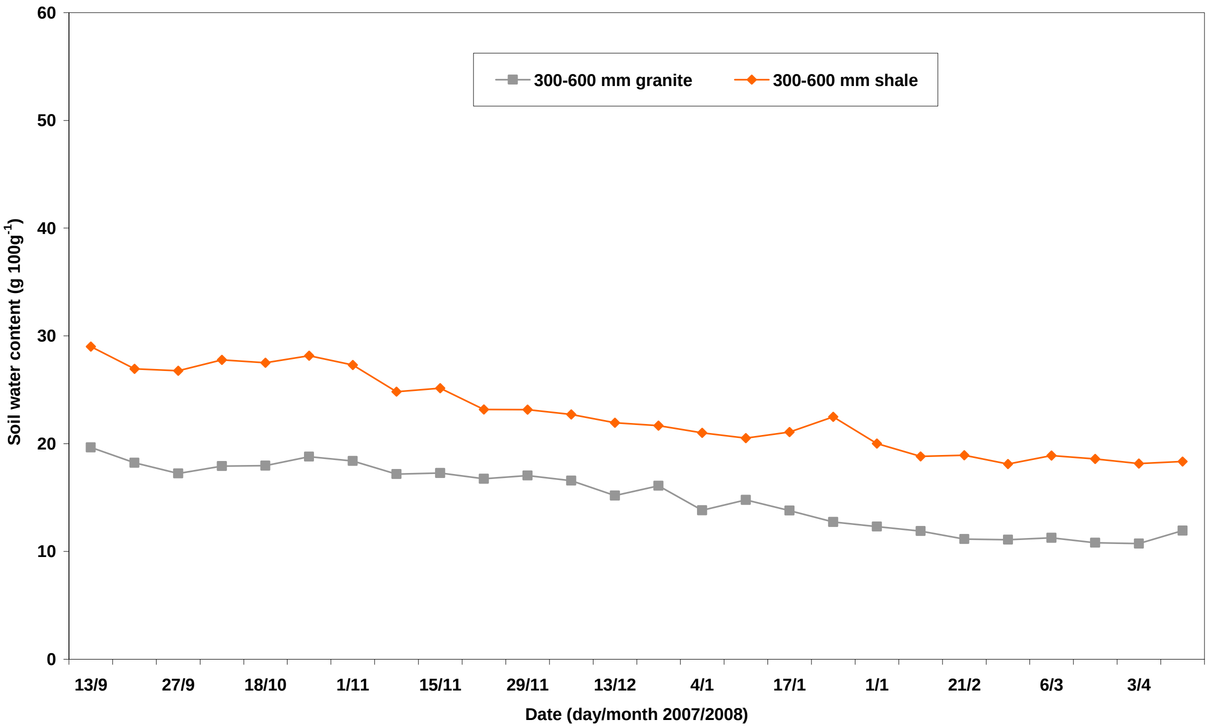

Figure 3.4b Soil water content during the 2007/2008 season for granite- and shale- derived soils (300-600 mm) in a Cabernet Sauvignon vineyard (C2) in Helderberg.

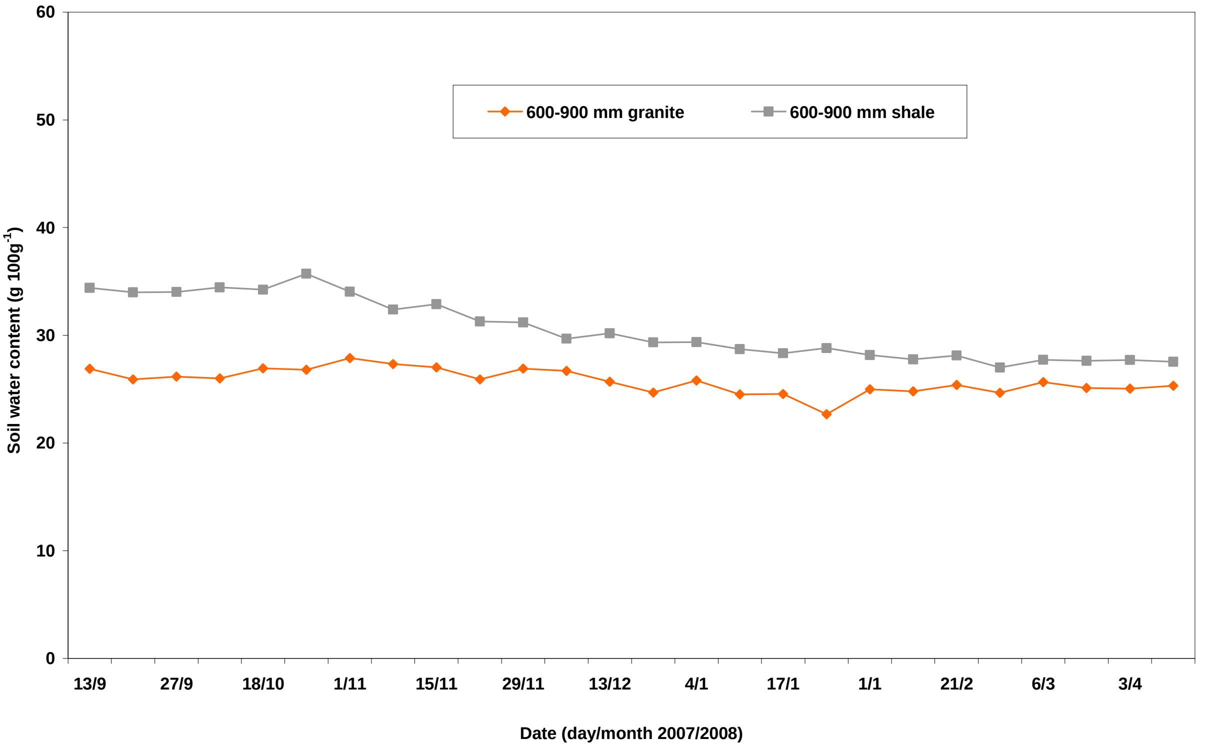

Figure 3.4c Soil water content during the 2007/2008 season for granite- and shale- derived soils (600-900 mm) in a Cabernet Sauvignon vineyard (C2) in Helderberg.

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Appendix 4A

Table 4.1 Nutrient status of Sauvignon blanc (S1, S2) and Cabernet Sauvignon (C1, C2) vineyard soils of different parent materials (granite and shale) in the Helderberg area (values indicate means per soil type, n = 12).

Element	Sauvignon blanc vineyards						Cabernet Sauvignon vineyards					
	A		B1		B2		A		B1		B2	
	Granite	Shale	Granite	Shale	Granite	Shale	Granite	Shale	Granite	Shale	Granite	Shale
Total N (%)	0.12	0.12	0.09	0.09	0.07	0.09	0.12	0.13	0.09	0.1	0.07	0.06
NO_3-N (mg ℓ$^{-1}$)	1.04	0.79	0.57	0.56	0.75	0.48	0.63	1.62	0.34	0.45	0.32	0.15
P (mg kg^{-1})	21.50	24.00	3.00	2.00	2.00	1.50	18.50	34.50	3.50	2.50	1.00	1.00
$K_{soluble}$ (mg ℓ$^{-1}$)	6.55	6.48	4.46	2.68	3.02	1.97	5.31	5.67	3.11	2.78	1.41	1.84
$K_{exchangeable}$ (cmol$_c$ kg^{-1})	0.49	0.56	0.32	0.32	0.2	0.19	0.37	0.4	0.23	0.19	0.13	0.11
$Ca_{soluble}$ (mg ℓ$^{-1}$)	2.01	1.53	1.05	3.43	1.75	2.72	2.17	1.75	1.16	1.72	0.81	1.75
$Ca_{exchangeable}$ (mg ℓ$^{-1}$)	4.26	6.19	1.98	3.73	1.65	2.71	5.73	3.93	3.07	1.79	1.68	1.1
$Mg_{soluble}$ (mg ℓ$^{-1}$)	0.35	0.27	0.2	0.75	0.29	0.41	0.53	0.66	0.46	0.49	0.31	0.36
$Mg_{exchangeable}$ (cmol$_c$ kg^{-1})	0.92	0.98	0.38	0.47	0.4	0.53	1.03	0.99	1.01	0.5	1.21	0.45

APPENDIX 4B

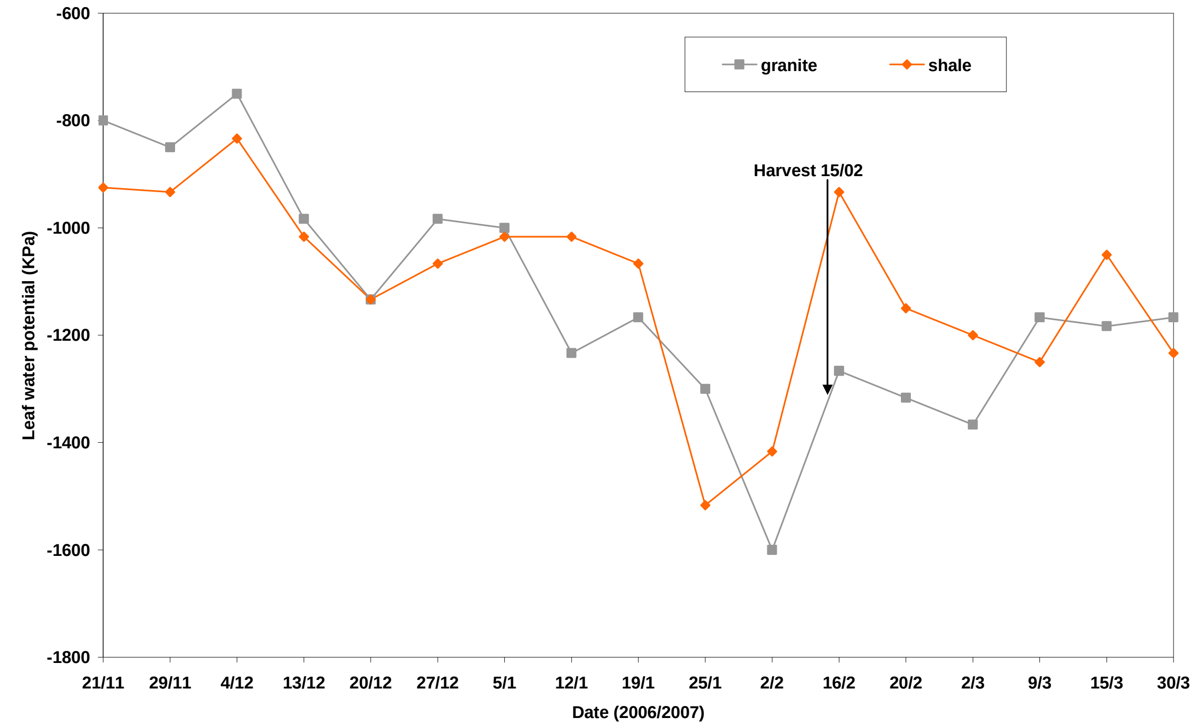

Figure 4.1a Midday leaf water potential (ψ_{leaf}) during the 2006/2007 season of Sauvignon blanc vines on granite- and shale-derived soils at S2.

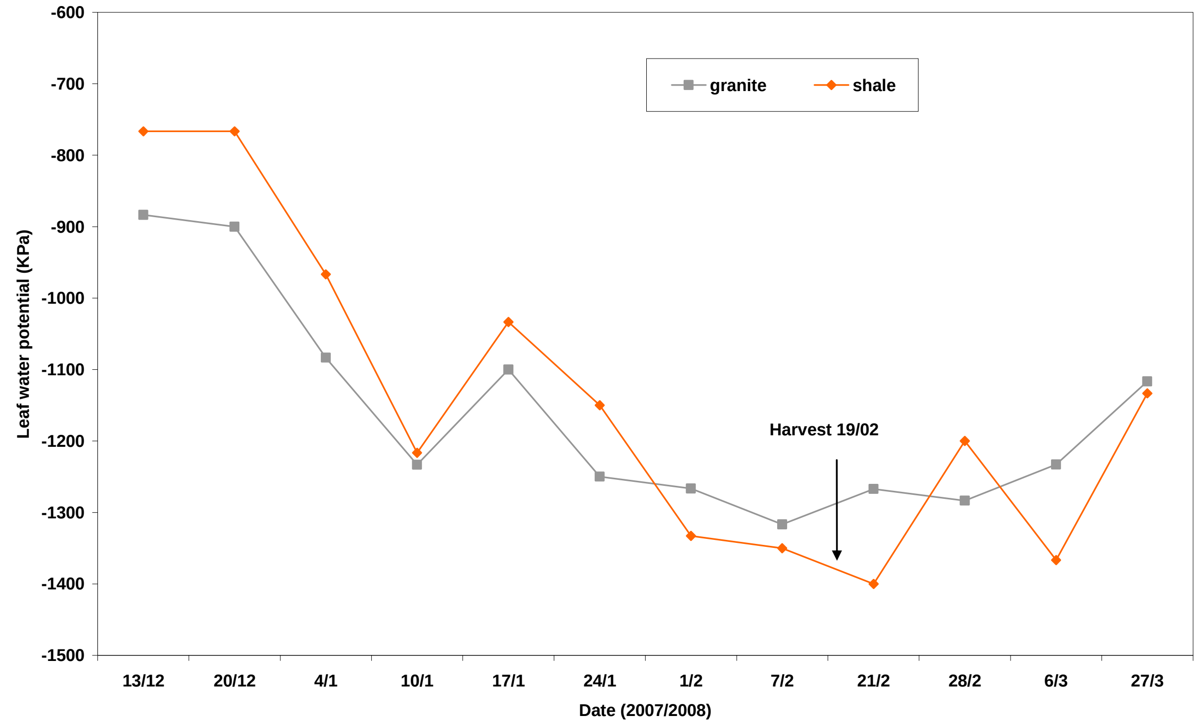

Figure 4.1b Midday leaf water potential (ψ_{leaf}) during the 2007/2008 season of Sauvignon blanc vines on granite- and shale-derived soils at S2.

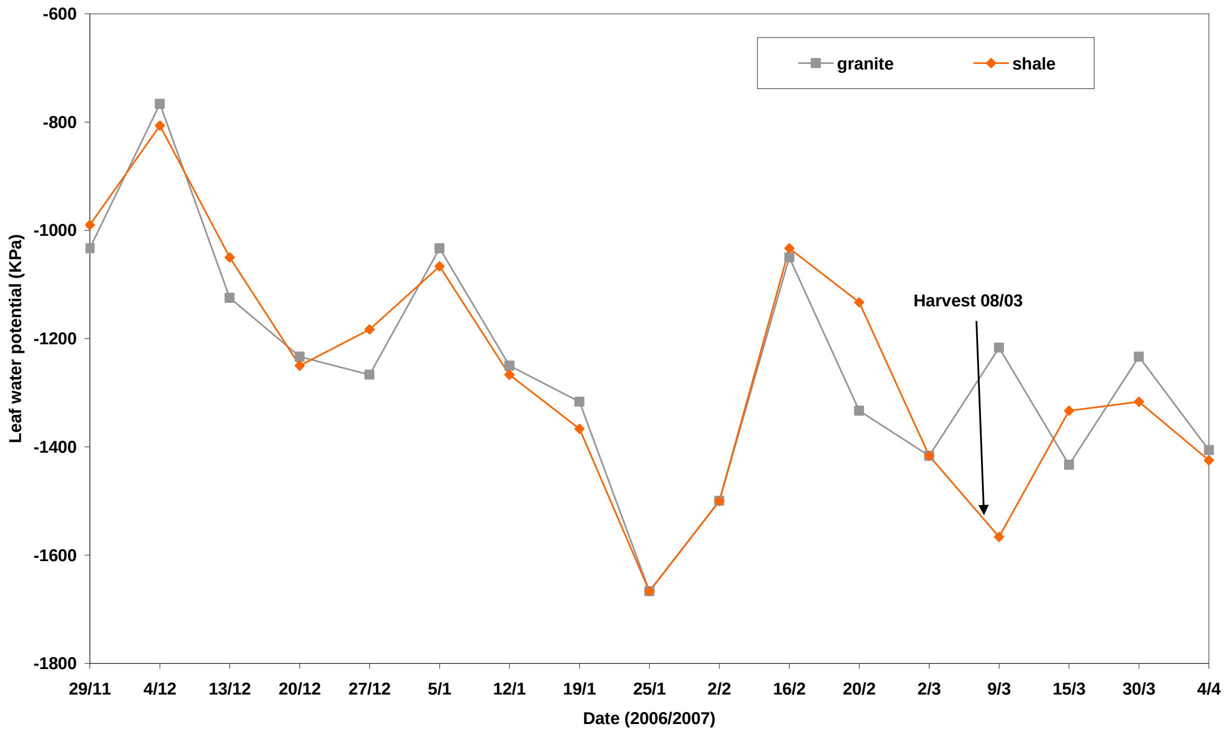

Figure 4.2a Midday leaf water potential (ψ_{leaf}) during the 2006/2007 season of Cabernet Sauvignon vines on granite- and shale-derived soils at C1.

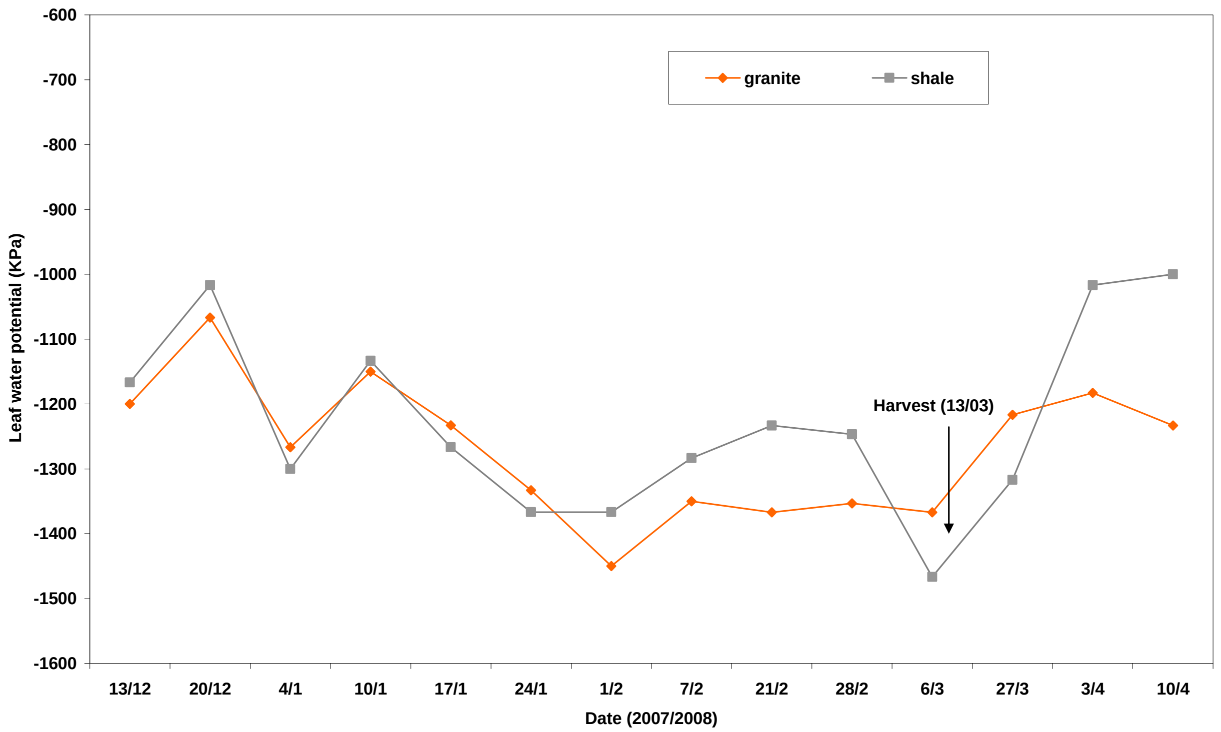

Figure 4.2b Midday leaf water potential (ψ_{leaf}) during the 2007/2008 season of Cabernet Sauvignon vines on granite- and shale-derived soils at C1.